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DYNACTOR SCRUBBER EVALUATION

D. W. Cooper, et al

GCA Corporation

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DYNACTOR SCRUBBER EVALUATION

by

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ABSTRACT

A novel aspirative spray scrubber, the Dynactor (RP Industries, Hudson, Massachusetts), was tested for power consumption and collection efficiency at three flow rates, two temperatures, two dust loading levels, for two different dusts. Higher efficiencies were fostered by: lower flow rate, lower inlet temperature, and higher mass loading. The collection efficiency of the Dynactor was not substantially different from that expected for a well-designed venturi scrubber operating at the same power level and air flow rate. As with other scrubbers of similar power consumption, collection efficiency decreased sharply for fine particles smaller than $1\text{ }\mu\text{m}$ aerodynamic diameter.

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SECTION I

CONCLUSIONS

This evaluation was one of a series of such evaluations being conducted by the Control Systems Laboratory of the Environmental Protection Agency to identify and test novel devices which are capable of high efficiency collection of fine particulates. The test methods used were not the usual compliance-type methods but were, rather, state-of-the-art techniques for measuring efficiency as a function of particle size using cascade impactors upstream and downstream from the control device. The Dynactor was not found to be substantially different in efficiency from venturi scrubbers, which also produce collection of particles by spray droplets that are in motion relative to the gas stream. As shown in Figure 21 of this report, the power consumption for the Dynactor was not substantially different from that for a well-designed venturi scrubber giving the same particulate collection efficiency. The following were associated with higher scrubber collection efficiency: lower inlet temperature, lower air flow rate, higher particle mass concentration, higher nozzle pressure, and the addition of surfactant material.

SECTION II
RECOMMENDATIONS

In those applications for which a scrubber might be suitable, the use of a Dynactor scrubber could be considered.

SECTION III

INTRODUCTION

This work was done to evaluate the Dynactor scrubber with respect to its mass collection efficiency as a function of particle size, the effect of several parameters on this efficiency, the air-moving capability and power consumption of the device, and its cost.

The Dynactor uses a proprietary nozzle design to produce a water spray which serves as an air eductor and as a scrubber, thus cleaning and propelling the gas simultaneously. A description of the Dynactor, written by its manufacturer (RP Industries, Hudson, Massachusetts), is in Appendix A. We tested one of the smaller units of its type, a two-stage device with a nominal rating of $0.47 \text{ m}^3/\text{s}$ (1000 cfm), Model DY 12 F2. The Dynactor was installed in a test setup at GCA/Technology Division and the following measurements were made:

- Air flow and pressure gain versus spray nozzle pressure
- Electrical power consumption versus spray nozzle pressure
- Mass collection efficiency as a function of particle aerodynamic diameter at two levels of flow, temperature, and concentration, for two different dusts, in a balanced test matrix
- Mass collection efficiency as a function of particle size for several additional sets of conditions
- Total mass collection efficiency at the conditions noted above

The dust was generated by a dust feeder - air ejector combination. Dust concentration was determined by gravimetric analysis of filter samples

obtained by isokinetic sampling upstream and downstream from the Dynactor. The concentrations in a set of aerodynamic size intervals were obtained from gravimetric analysis of samples obtained by identical impactors, one placed upstream and the other downstream from the Dynactor, from which data the mass collection efficiency as a function of particle size was obtained. These data were analyzed using an F-test analysis of variance to determine which factors had significant influence on collection efficiency in the various aerodynamic size fractions and to estimate experimental uncertainty. Flow was measured using pitot tube traverses and pressure gain was measured using Magnehelic pressure gauges.

The work also included some cost estimates, from which certain comparisons can be made with other control devices. Comparisons with other experimental results for spray scrubbers have also been made, especially with regard to which factors can enhance collection efficiency.

SECTION IV

TEST EQUIPMENT AND PROCEDURE

Most of the experimental work was done with the equipment shown in Figures 1 and 2. This equipment allowed us to measure collection efficiency as a function of particle size as well as the conditions of flow, concentration, temperature, pressure drop, etc. which prevailed during the efficiency tests.

Figure 1 gives the overall picture of the test setup. Dust from a screw feed was picked up by an air ejector/aspirator and blown into ducting leading to the Dynactor. The flow in the ducting was produced by the Dynactor and the relatively weak fan of the heater/blower, sometimes in conjunction with the fan shown at the very end of the flow train. Upstream, the turbulent mixture was sampled five or more duct diameters from the dust feed by an Andersen Model III cascade impactor, usually run with isokinetic flow, and by a filter assembly (glass fiber absolute filter, 47-mm diameter) which always was operated isokinetically. An identical sampling combination was used downstream, as described more fully in Figure 2. The temperature and pressure of the mixture entering the Dynactor was measured as was, sometimes, the temperature of the mixture leaving the Dynactor. The pressure drop or gain across the device was measured. Each of the major components of the test equipment will be described in greater detail next.

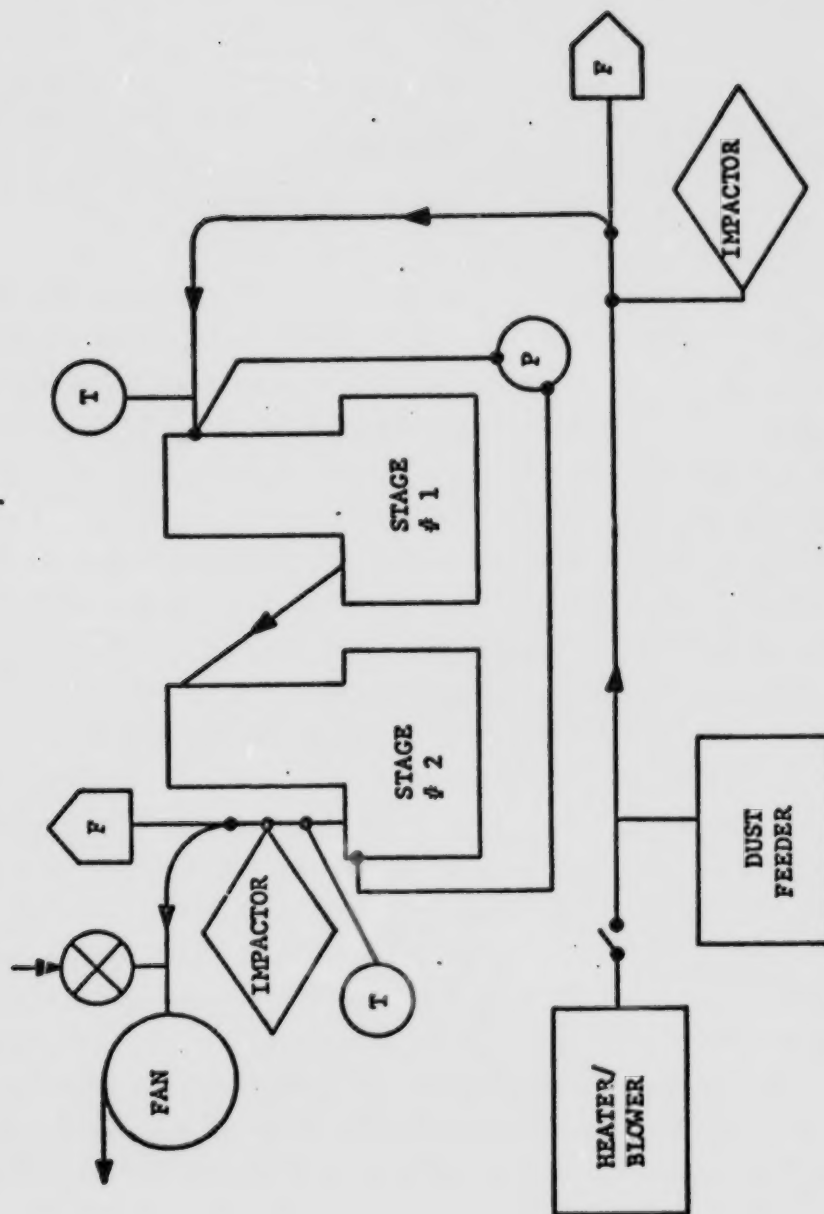


Figure 1. Test system for Dynaject two-stage scrubber evaluation, including filter samplers (F), thermometers (T), and pressure gauge (P)

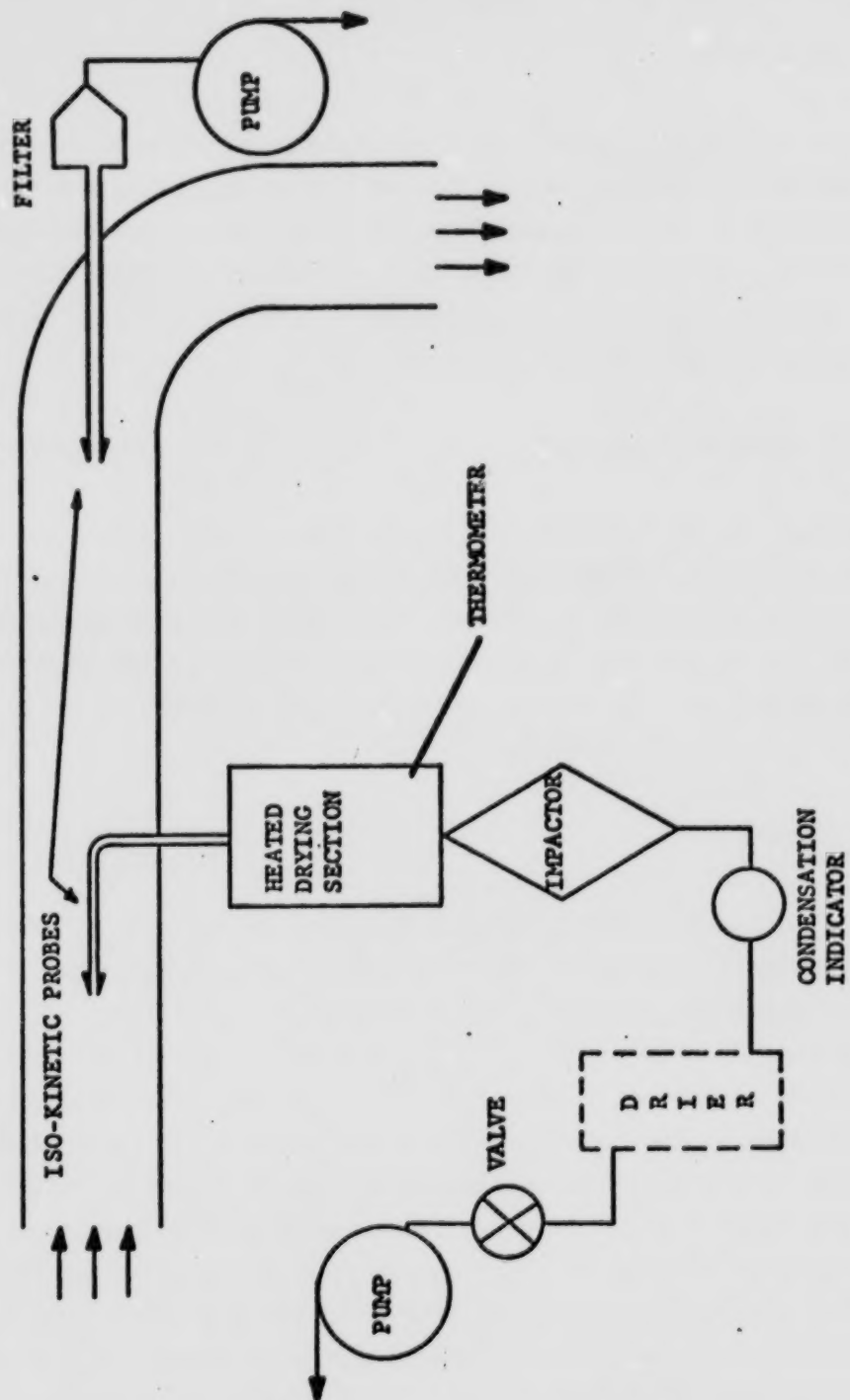


Figure 2. Details of aerosol concentration and size distribution measurement sections

HEATER/BLOWER

The heater burned propane supplied continuously from a pressurized tank. Propane was selected because its combustion products are almost exclusively carbon dioxide and water, with a negligible production of carbon aerosol. The heater was rated at a maximum of 350×10^3 Btu/hr (1.0×10^5 watt). Its blower could provide $0.66 \text{ m}^3/\text{s}$ (1400 cfm) maximum flow.

DUST FEEDER AND ASPIRATOR

The dust feeder (Acrison, Inc. Model 120) operated with a vibrating hopper that channeled the dust into a cavity from which a screw feeder directed an adjustable constant volume flow to the aspirator. The aspirator was powered with pressurized air at 80 psig (5630 cm WC above atmosphere) and blew the dust into the main ductwork while deagglomerating the aerosol material.

IMPACTORS

Upstream and downstream from the Dynactor, we used the Andersen Model III in-stack impactor to size-fractionate the aerosol. Except for early tests which were run at 28 lpm (1 cfm or $4.7 \times 10^{-4} \text{ m}^3/\text{s}$), the impactors were operated at 14 lpm to lessen the likelihood of particle rebound, as advised by its manufacturer. The impactors were used with the glass fiber media impaction substrates designed for them. (Later in this report is a description of some tests done to ascertain weight changes in the impactor substrates due to causes other than the accumulation of particulate material.) The temperature of the impactor at the Dynactor outlet and its drying section (Figure 2) was kept about 20°C above the temperature of the Dynactor exhaust stream to produce drying of the droplets present in the exhaust. The drying section volume was $2.4 \times 10^{-3} \text{ m}^3$ (75 cm long by 6.4-cm diameter), which yielded a residence time of 10 seconds.

Preliminary tests showed that the concentrations downstream from the Dynactor scrubber were much lower than those upstream. To obtain enough material on the downstream impactor for weighing and yet not too much material on the upstream impactor (to prevent rebound and reentrainment), it was necessary to run these impactors for different total durations, the downstream impactor sampling for about 10 times as long as the upstream impactor. The total downstream sampling time was divided into equal intervals, and the upstream samples were taken with their (shorter) durations centered on the midpoints of the intervals, to lessen error due to time fluctuations of concentration and to facilitate error analysis. The upstream samples had to be taken for a fraction of the total downstream sampling duration to prevent overloading the impactor.

The upstream impactor drifted to a higher flow rate than the downstream impactor, during the course of the tests. The difference averaged about 10 percent, but was offset by the nearly equal reduction in upstream sampling volume due to the clean air present in the heating chamber at the start of each upstream sample. The flow difference would have produced a 5 percent difference in aerodynamic diameter between the impactors, which was negligible.

The concentrations were determined from weight changes in the filters and impaction substrates. To ascertain the reproducibility of our weighing measurements, we made 18 weighings each of two weights, 10 g and 100 mg, over 8 days. We obtained 16 readings of 9.9994 and two of 9.9993 g, and 14 readings of 0.1000 and four of 0.1001 g, from which we concluded our reproducibility was better than 0.1 mg.

METTLER BALANCE (H15) AND WEIGHING ERRORS

The Mettler balance has a vernier scale which allowed the weight to be read to 0.1 mg. This would place its precision at about 0.05 mg and the error in taking the difference of two weights at about 0.1 mg standard deviation.

To check whether or not dessication made a substantial difference in the impactor substrate material, we made 24 weighings before and after desiccating the substrates for 24 hours. The mean change in weight was 0.15 mg loss (for substrates averaging 0.20 g) and 11 of the 24 changes were 0.1 mg. From this we decided to dessicate the substrate material before making the tare weighing as well as before making the weighing with the captured particulate material.

Precautions were taken to enhance weighing accuracy for all efficiency tests. The substrates were dessicated at least 12 hours. A static charge eliminator was used in the Mettler analytical balance. The substrates were weighed singly; also, the weights of groups of four were compared with the sum of the four individual weights. To lessen the likelihood of the wrong substrate being ascribed to a given impaction stage, the substrates were numbered so that their last digit was the same as the stage with which they were to be used.

COMPARISON OF ANDERSEN MARK III IN-STACK CASCADE IMPACTORS

In a comparison test done before the Dynactor efficiency tests, the two identical impactors were used to sample the same aerosol, iron oxide powder generated from a Wright dust feeder into a wind tunnel. Each impactor drew 28 lpm (1 cfm) from a Y-connection that was connected to a single sampling probe. The results of this test are given in Tables 1 and 2 and in Figure 3. The "reclaimed" media were rinsed in methanol and reused. The correlation coefficient for the mass captured on the corresponding stages of the impactors was 0.998, indicating very close matching. The data also indicate the impaction substrates can be reclaimed by rinsing with methanol, which is significant, as they cost nearly \$1.00 apiece.

Table 1. DATA FROM TWO ANDERSEN MARK III CASCADE IMPACTORS SAMPLING SAME IRON OXIDE AEROSOL (MAPICO BLACK) AT 28 ℓ pm (1 cfm, $0.47 \times 10^3 \text{ m}^3/\text{s}$) ON NEW MEDIA

Impactor Stage	Mass collected		Percentage of total mass		Cumulative mass percentage		Effective Diameter (μm) D_{50}
	Impactor #4601	Impactor #4602	Impactor #4601	Impactor #4602	Impactor #4601	Impactor #4602	
1	0.4	0.2	2	1	2	1	9.6
2	0.3	0.2	2	1	4	2	6.0
3	0.6	0.4	3	2	7	4	4.0
4	0.8	0.7	5	4	12	8	2.75
5	2.0	1.9	11	11	23	19	1.75
6	3.6	9.7	54	55	77	74	0.9
7	3.3	3.8	19	22	96	96	0.54
8	0.1	0.2	1	1	97	97	0.36
Filter	0.6	0.5	3	3	100	100	0.0
Total Mass	17.7	17.6	100	100			

Correlation coefficient: 0.998

Table 2. DATA FROM TWO ANDERSEN MARK III CASCADE IMPACTORS SAMPLING SAME IRON OXIDE AEROSOL (MAPICO BLACK) AT 28 μ m ON RECLAIMED MEDIA (FINAL FLOW IN #4601 WAS ABOUT 5 PERCENT LESS THAN THAT OF #4602)

Impactor Stage	Mass collected		Percentage of total mass		Cumulative mass percentage		Effective Diameter (μ m) D_{50}
	Impactor #4602	Impactor #4601	Impactor #4602	Impactor #4601	Impactor #4602	Impactor #4601	
1	0.1	0.1	1	1	1	1	9.6
2	0.1	0.1	1	1	2	2	6.0
3	0.4	0.3	2	2	4	4	4.0
4	0.7	0.6	3	3	7	7	2.75
5	2.2	1.8	12	10	19	17	1.75
6	11.3	10.6	59	59	78	76	0.9
7	3.5	3.6	18	19	96	95	0.54
8	0.1	0.4	1	2	97	97	0.36
Filter	0.6	0.6	3	3	100	100	0.0
Total Mass	19.0 g	18.1 g	100	100			

Correlation coefficient: 0.999

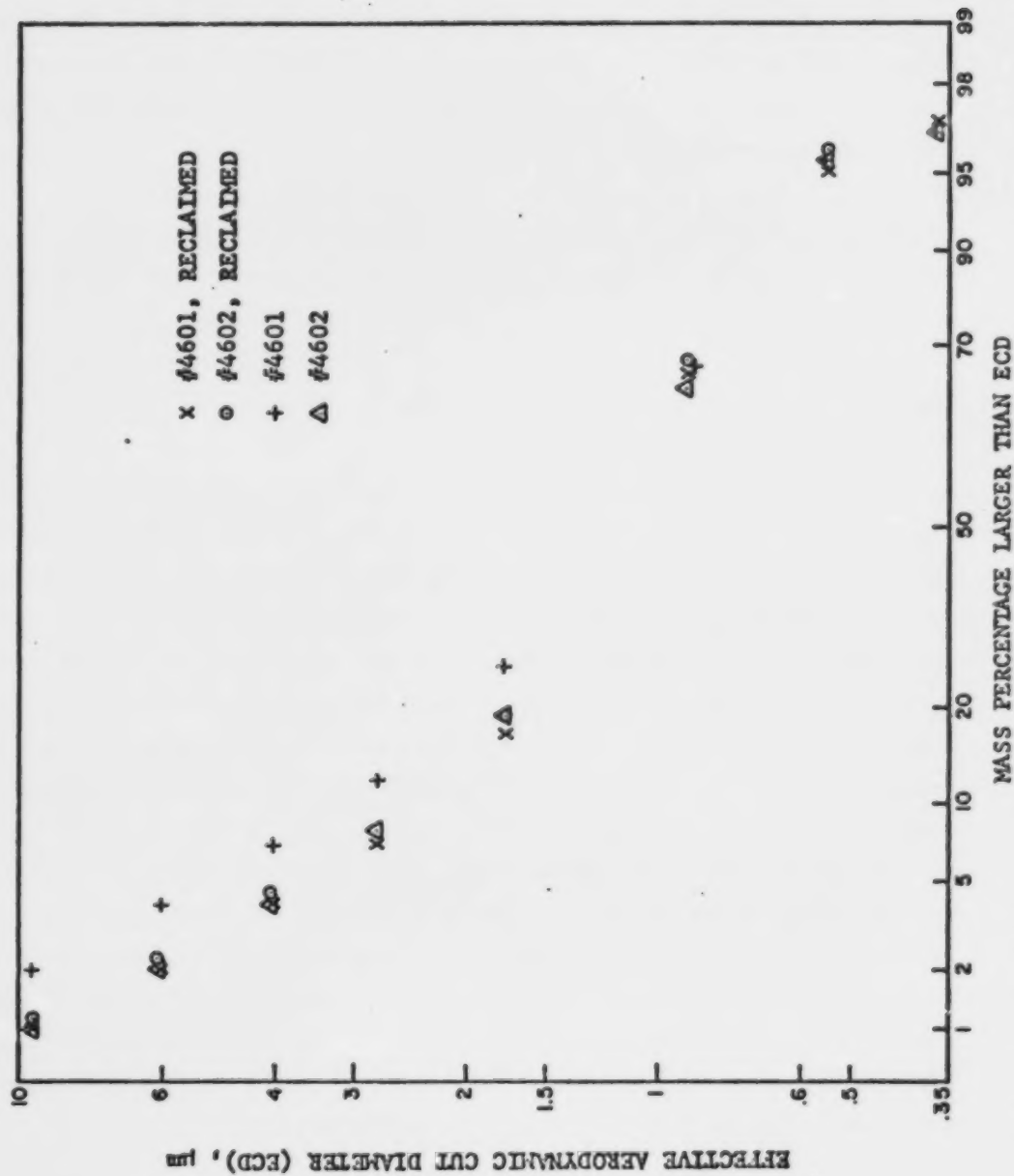


Figure 3. Cumulative mass size distribution of iron oxide pigment aerosol as determined by two impactors (#4601 and #4602) with original substrates and with reclaimed substrates. Aerosol generated by Wright dust feeder

As we have noted, the standard deviation of the difference between two weighings (the net weights, that is) should be about 0.1 mg; from the data in Tables 1 and 2, it can be seen that two-thirds of the net weights for the aerosol material caught in the impactors were within 0.1 mg of each other. The ratios of the weights for corresponding stages diverged from near unity only when the weights approached 0.1 mg, as expected from the weighing precision.

These comparison tests show that the impactors are nearly identical in performance, which is what was desired for the tests of the Dynactor collection efficiency.

LOSSES FROM IMPACTION SUBSTRATE MATERIAL

Bird *et al.*¹ have reported that the substrate material used in the impactor, cut from glass fiber filters, showed a tendency to lose weight in handling and use. At the beginning of our tests we weighed four such substrates before and after inserting them into and removing them from the impactor, and we found an average weight loss of 0.1 mg per substrate. Subsequent tests in which we sampled the aerosols produced some very lightly loaded substrates that showed weight losses $\geq$ 0.1 mg. Blowing off the substrates before using them visibly removed some loose material. Rinsing the substrates in methanol before using them removed an average of 1 mg of loose solid material per substrate. There was noticed some losses in weight even with the procedure of rinsing with methanol, desiccating for 12 hours or more, weighing, using, desiccating again, weighing again. To estimate this loss we wanted to determine an average weight loss due to handling and sampling, so we sampled filtered air for 2 hours at 0.5 cfm. The average loss was 0.23 mg per substrate. All of these loss tests are tabulated in Table 3.

The first column of Table 3 briefly describes how the impactor substrate material was treated before it was tested; either it was used

Table 3. ANDERSEN MODEL III IMFACTION SUBSTRATE LOSSES

Treatment	Test conditions (and number of substrates)	Weight loss (mg)	Number
Untreated	Load and unload (4)	-0.1	4
Most washed in methanol	Sample aerosols (176)	-0.1	8
		-0.2	9
		-0.3	2
		-0.4	2
		-0.5	0
		-0.6	4
		average loss: -0.26	
Washed in methanol	Sample filtered air (8) for 2 hours, at am- bient temperature	-0.1	2
		-0.2	3
		-0.3	2
		-0.4	1
		average loss: -0.23	
Washed in methanol	Sample filtered air (8) for 15 minutes, am- bient temperature	-0.1	5
		-0.2	1
		-0.3	1
		average loss: -0.12	

as it came from the manufacturer (untreated) or it was washed in methanol and dried again. The second column tells how the substrate was used in the tests: either just loaded into the impactor and then unloaded immediately or loaded, used to sample a test aerosol as part of the efficiency tests, and unloaded or loaded, used to sample filtered air, and unloaded. The weight loss is the difference between the substrate weight before the test and the weight after the test; the losses listed for the substrates used to sample the aerosols are the losses for the substrates which showed any loss, 25 of the 176 substrates from a series of 11 efficiency tests, which substrates were invariably very lightly loaded (visual inspection). The fourth column gives the number of substrates having the indicated loss. These tests led to the following treatment of the data obtained with the cascade impactor for the analysis of variance tests:

1. Weight changes of 0.3 mg or less were taken to be ≤ 0.3 mg for calculation of efficiencies, which efficiencies are given as inequalities.
2. Weight changes of 0.4 mg or more were used without correction.

Data treatment is discussed in Section VI.

In Section VI, we have made best-case and worst-case analyses of the weighing errors and substrate weight losses. The best case is obtained by overestimating the inlet concentration (adding 0.3 mg to the weight change for possible substrate weight loss and adding 0.1 mg for precision uncertainty) and underestimating the outlet concentration (subtracting the 0.1 mg uncertainty). The worst case is obtained by overestimating the outlet (+0.4 mg) and underestimating the inlet (-0.1 mg). From the tables and figures in Section VI it can be seen that the differences between the best-case analysis and the worst-case analysis are not great enough to change appreciably our conclusions.

DUCTING

For the tests conducted at flow rates of 500 cfm ($0.24 \text{ m}^3/\text{s}$) and 1000 cfm ($0.47 \text{ m}^3/\text{s}$) the sheet metal ducting upstream from the Dynactor was 8 inches in diameter by about 12 feet long (0.20 m diameter by 4 m long) connected to an expander to take it from 8-inch diameter to 16-inch diameter (0.20 m to 0.40 m), followed by a 90° elbow, 6 feet (2 m) more 16-inch ducting and another 90-degree elbow connected to the Dynactor inlet. For the 1500 cfm ($0.71 \text{ m}^3/\text{s}$) tests, the first section was about 8 feet (3 m) of 12-inch diameter (0.30 m) ducting. The dust feeder was separated from the sampling probes by about 6 feet (2 m). The Dynactor outlet had a reducer to go from the 16-inch diameter (0.40 m) ducting to 8-inch diameter ducting (0.20 m), and the sampling probes were about 3 feet (1 m) from the reduction.

FLOW PROFILES IN DUCTING

The tube inlets for sampling the dust concentrations upstream and downstream from the Dynactor scrubber were set up to be no less than four diameters downstream from flow disturbances and 1.5 diameters upstream. The flow velocity profiles in the immediate vicinity of the sampling positions were measured to see that they approximated the turbulent flow profiles expected. By the Reynolds analogy, such a matching would be a good indication of fairly homogeneous aerosol mixing. Good mixing is expected because the Reynolds numbers in the ducting are at least 1×10^5 and the sampling points are about 5 diameters or greater downstream from the point of aerosol generation. The traverses were done at the positions labeled "impactor" in Figure 1. Figure 4 shows the velocity profile obtained at the 8-inch (0.20 m) diameter ducting upstream (for somewhat different flow rates).

Preliminary tests at the inlet indicated a typical, nearly flat, turbulent flow profile without the heater blower on, but the flow

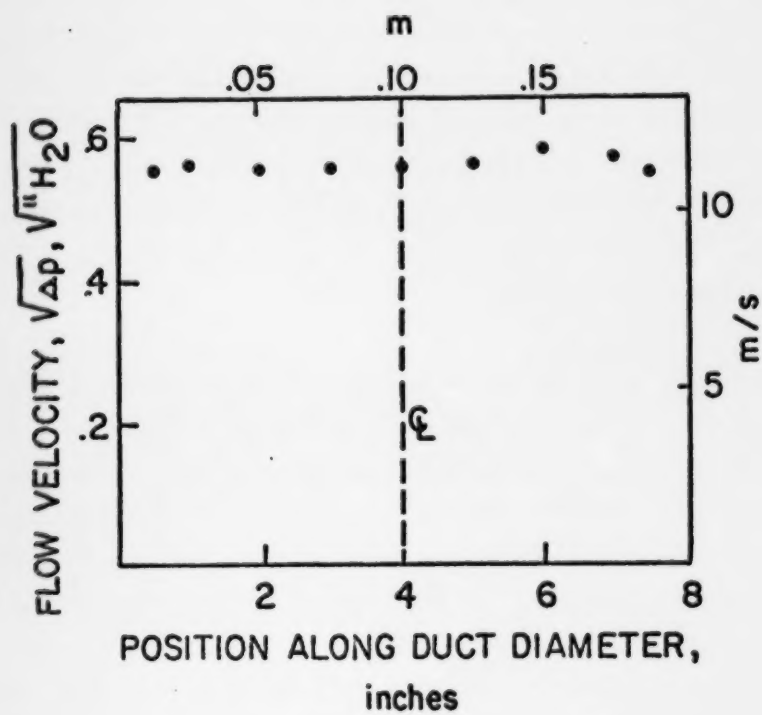


Figure 4. Flow velocity profile in inlet ducting, Dynactor test setup

exhibited swirl once the heater blower was used. Installation of baffling, two 4-inch diameter (0.10 m) ducting pipes about 2 feet long (0.2 m) immediately downstream from the blower, virtually eliminated the swirl effect; Figure 4 was obtained with the blower on. A more detailed pitot traverse was made at the downstream sampling position. The results of eight-point and twelve-point traverses made downstream are given in Figure 5, along with centerline measurements. The flow closely approximates the turbulent flow expected, with no pronounced anomalies. The total volume flow from the equal-area, eight-point traverse was compared with that from the equal-area, twelve-point traverse: for the two such comparisons we made, they agreed within 5 percent and within 2 percent. Figure 6 shows the centerline measurements made simultaneously with the eight-point traverse measurements used to characterize Dynactor air-moving capability; reproducibility was judged adequate for the use of the centerline pitot reading to set the Dynactor flow at the 0.24, 0.47, 0.71 m^3/s (500, 1000, and 1500 cfm) levels when testing the Dynactor fractional collection efficiency.

The flow rates reported for the Dynactor are actual volume flows rather than standard volume flows, and they were generally determined by the center-line reading of the pitot tube in the duct downstream from the Dynactor.

This completes this section on the equipment used in the Dynactor evaluation and some of the tests performed on this equipment.

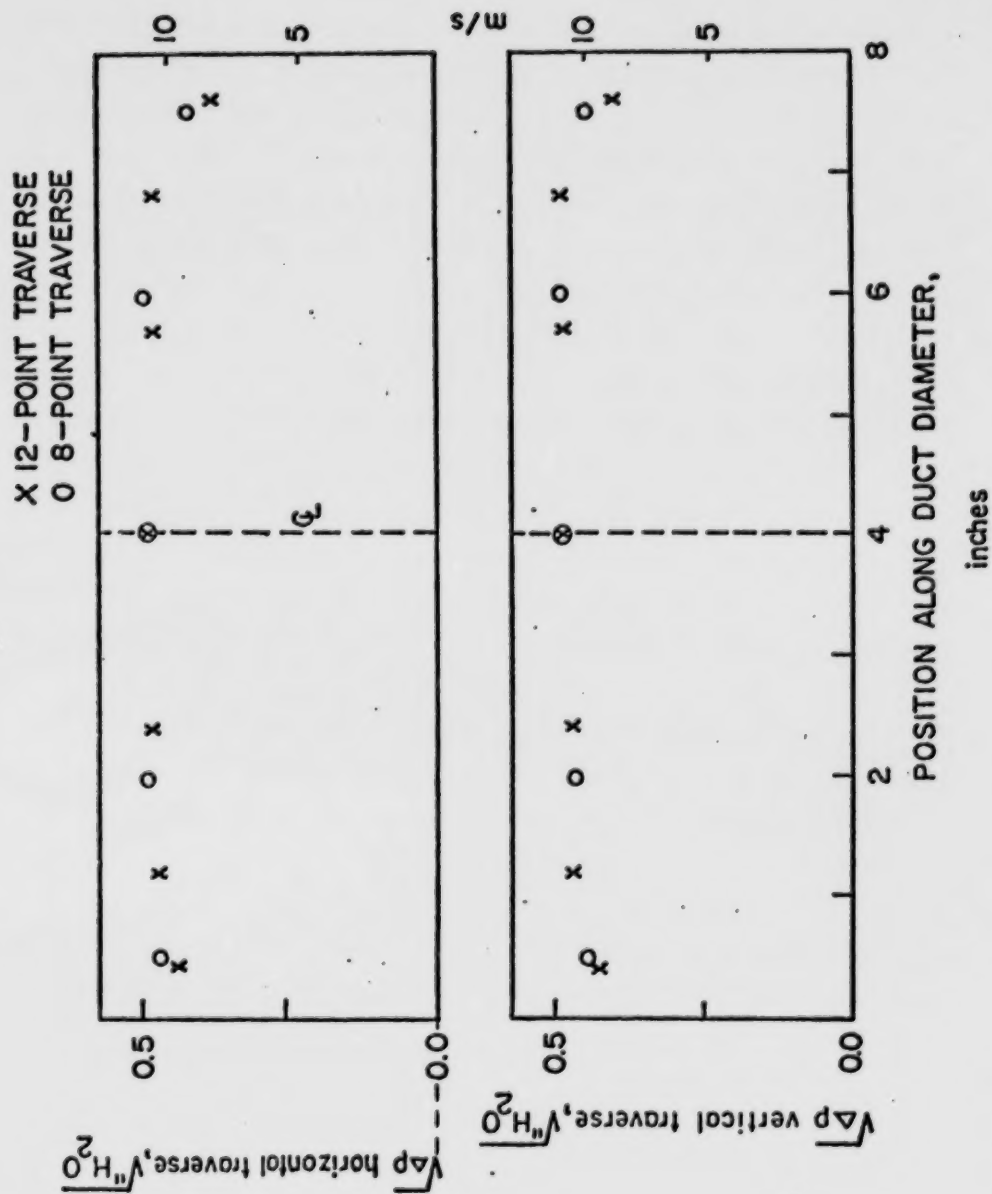


Figure 5. Flow velocity profile in outlet ducting, Dynactor test setup

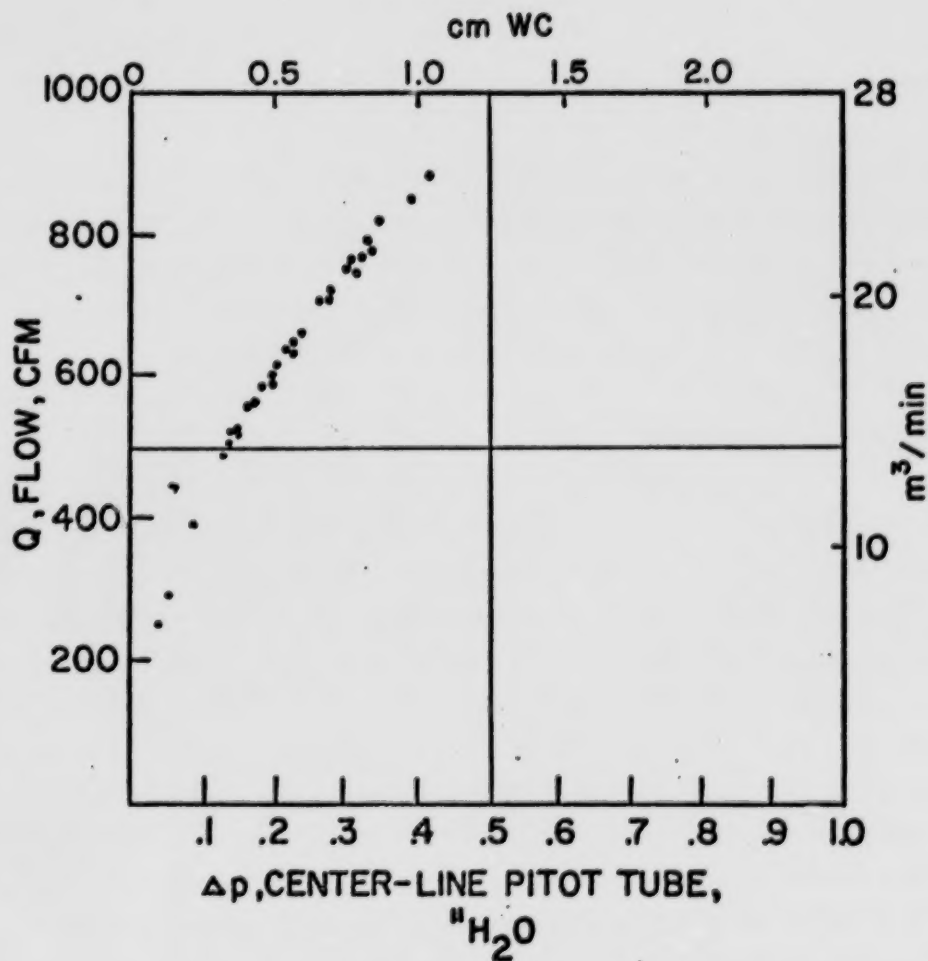


Figure 6. Volume flow rate versus center-line reading with pitot tube, Dynactor test setup

SECTION V

RESULTS

INTRODUCTION

This section contains the results of the work done to characterize the Dynactor's air-moving capabilities, power consumption, and collection efficiency on a mass basis as a function of particle size, determined with cascade impactors. In Section VI these results will be discussed and the Dynactor compared with venturi scrubbers.

AIR-MOVING CAPABILITIES

The Dynactor scrubber acts somewhat like a fan, providing a pressure boost rather than a pressure drop to air moving through it, up to some maximum flow which depends upon operating conditions. We tested the pressure gain from Dynactor inlet to Dynactor outlet with a pressure gauge connected to the inlet and outlet ports, as shown by P in Figure 1. The total air flow at 70°F was obtained from eight-point equal-area traverses in the 8-inch diameter duct immediately downstream from the Dynactor. The manufacturer informed us that the inlet of the device should not be at a vacuum in excess of 1/2-inch H₂O (1.2 cm WC). In our tests, we observed that for pressure differences across the device on the order of 1-inch H₂O (2.5 cm WC) or greater there was a significant accumulation of water spray in the upper plenum chambers of the device, indicating some disruption of the normal flow patterns, so only a few tests were done under such conditions. The

data for flow (at 1 atmosphere pressure and 70°F) versus pressure increase are given in Figure 7 for three different spray nozzle pressures, 100, 150, 200 psig (7.0, 10.6, 14.1 $\times 10^3$ cm WC). The usual operation of the device, according to the manufacturer, is with pressure differences less than or about 1/2 inch H₂O (1.2 cm WC). Table 4 has the data for the Dynactor flows with inlet and outlet open to the atmosphere and the pressure increases to be expected (no flow). The flows were somewhat less than expected by the manufacturer; the maximum pressures matched expectations.

POWER CONSUMPTION: PUMPS

The power consumption of the Dynactor pumps was measured -- using an ammeter, a voltmeter, and an oscilloscope (to determine power factor). The problems of scaling up the data to a typical application (air flow much greater than 1 m³/s) are such that it was decided the data might be misleading so they have not been presented.

POWER CONSUMPTION: DYNACTOR SPRAY NOZZLES

In an aspirative spray scrubber such as the Dynactor, the power for moving the air through the device is supplied by the pumps that power the spray nozzles. The electrical power consumption of an installation will depend upon the kind of motor and pump used in such systems. A fundamental measure of power consumption is the intrinsic nozzle power, the product of the pressure drop across the nozzle and the volume flow rate of fluid through the nozzle. The volume flow through the nozzle is the product of the fluid average velocity and the nozzle area:

$$Q_w = \bar{v}_w A. \quad (1)$$

The velocity is expected to be proportional to the square root of the pressure (potential flow):

$$\bar{v}_w \propto (\Delta p)^{1/2} \propto Q_w. \quad (2)$$

Figure 8 has the manufacturer's data plotted on a log-log graph to show flow versus pressure and intrinsic power versus pressure.

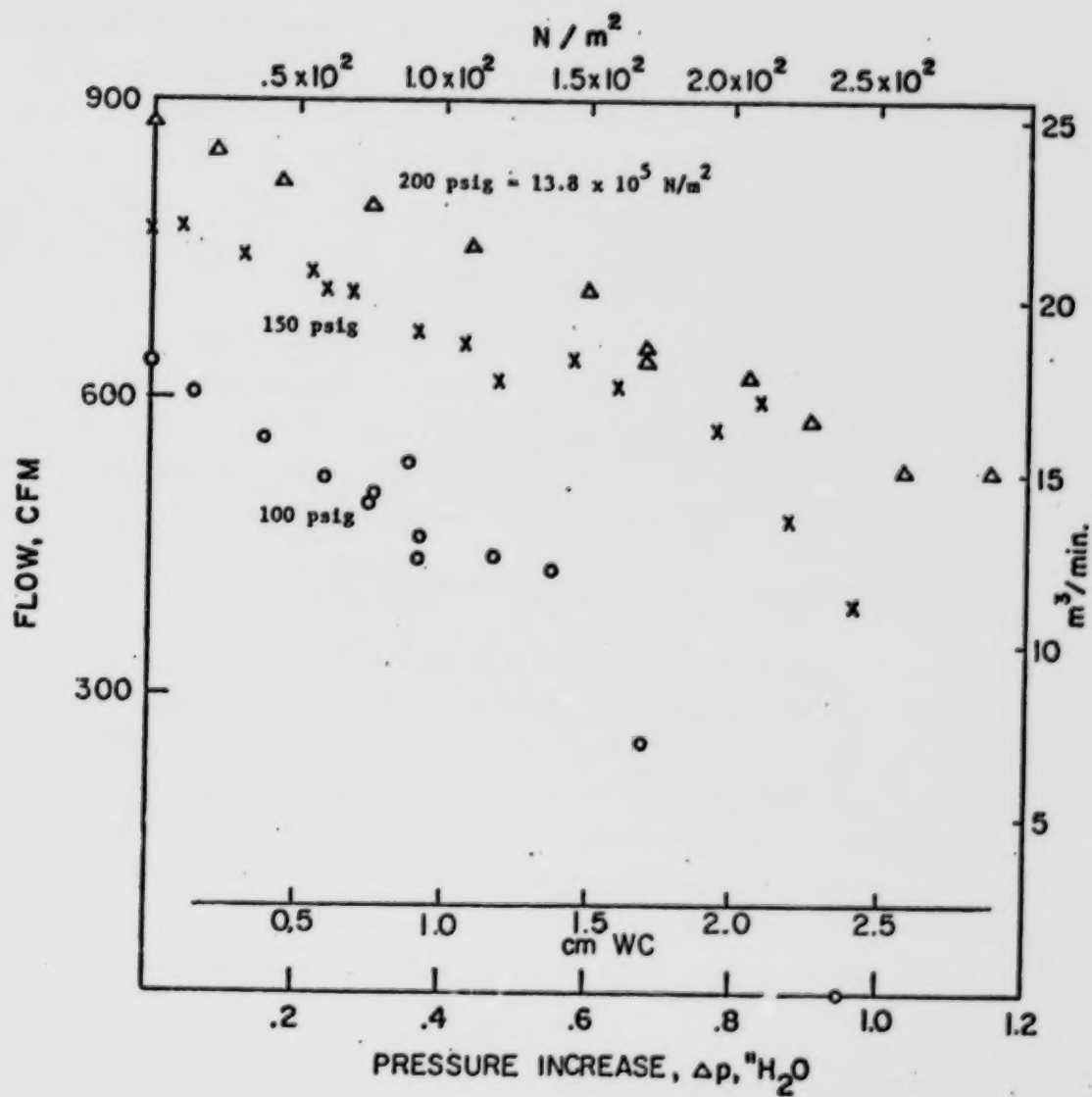


Figure 7. Pressure gain produced by Dynactor versus flow rate through it

Table 4. DYNACTOR AIR-MOVING CAPABILITIES: FLOW WITH INLET AND OUTLET OPEN TO ATMOSPHERE, MAXIMUM PRESSURE GAIN (NO AIR FLOW)

	Spray nozzle pressure		
	100 psig (7.0 x 10 ³ cm WC)	150 psig (10.6 x 10 ³ cm WC)	200 psig (14.1 x 10 ³ cm WC)
Unobstructed flow			
cfm	640	780	880
m ³ /min	18.1	22.1	24.9
m ³ /s	0.302	0.368	0.415
Maximum pressure gain			
inch H ₂ O	1.0	1.5	2.0
cm WC	2.5	3.8	5.0

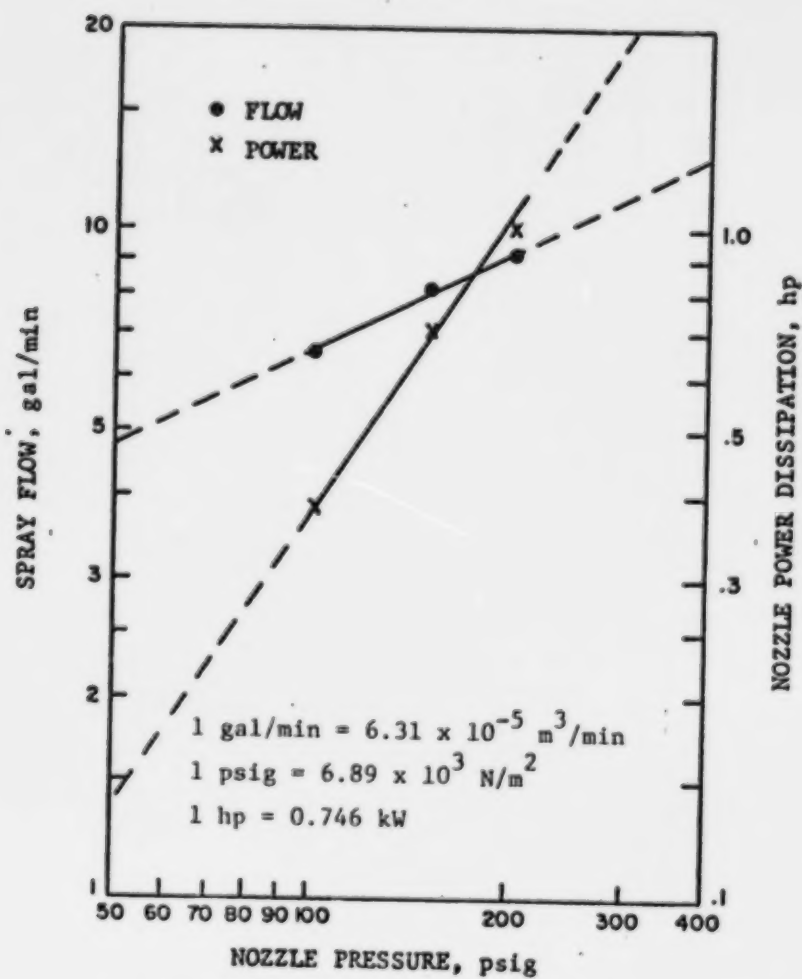


Figure 8. Dynactor spray flow and nozzle power dissipation versus spray pressure

The nozzle power dissipation is given by

$$P = Q_w \Delta p \quad (3)$$

$$P = (\Delta p)^{3/2} \quad (4)$$

for power P in watts, volume flow in m^3/s , and pressure drop Δp in cm WC. To obtain the power in horsepower, use

$$P_{\text{hp}} = 5.82 \times 10^{-4} Q_{\text{gpm}} P_{\text{psig}} \quad (5)$$

where the power is in horsepower, the flow in gallons per minute, and the pressure drop in pounds per square inch.

The manufacturer indicated that each nozzle had the following flow versus pressure: 6.6 gpm ($4.2 \times 10^{-4} \text{ m}^3/\text{s}$) at 100 psig (7.0×10^3 cm WC), 8.1 gpm ($5.1 \times 10^{-4} \text{ m}^3/\text{s}$) at 150 psig (10.6×10^3 cm WC), 9.2 gpm ($5.8 \times 10^{-4} \text{ m}^3/\text{s}$) at 200 psig (14.1×10^3 cm WC).

The power dissipation calculated for these three nozzle pressures is then: 0.38 hp (0.29 kW), 0.70 hp (0.52 kW), and 1.00 hp (0.74 kW). These values for power are also shown in Figure 8, and are consistent with the expected $(\Delta p)^{3/2}$ dependence of power on nozzle pressure.

WATER CONSUMPTION

The maximum amount of water used by the Dynactor is the volume flow rate through the spray nozzles. At 1000 cfm ($0.47 \text{ m}^3/\text{s}$), this is $2 \times 9.2 \text{ gal/min} = 18.4 \text{ gal/min}$ ($1.16 \times 10^{-3} \text{ m}^3/\text{s}$) or 18.4 gallons of water per 1000 ft^3 air treated ($2.47 \times 10^{-3} \text{ m}^3$ water per m^3 air treated), at standard conditions. If this could be recycled, as it was in our tests, actual consumption would be decreased.

TEMPERATURE LIMITATION

In preliminary testing, the Dynactor spray was started and the heater used to raise the temperature of the inlet gas to 300°F (200°C ± 5°C) while generating and sampling an iron oxide aerosol at 1 gr/ft³. Although we had hoped to be able to make tests at this temperature, the obvious damage done to certain plastic materials in the Dynactor made the device inoperable. It was agreed by all parties that future tests at elevated temperatures should be done at 200°F.

MASS COLLECTION EFFICIENCY VERSUS PARTICLE SIZE

The remainder of the section on results will contain material from tests done to determine collection efficiency, by mass, as a function of particle size, or more precisely as a function of particle aerodynamic diameter. The data from these tests are presented in Appendix B. Sizing was done by using Andersen Model III In-Stack Impactors at 14 lpm flow rate (0.5 cfm). The material on a given stage of the impactor was classified as being of an aerodynamic diameter greater than or equal to the aerodynamic cutoff diameter for that impaction stage and less than the aerodynamic cutoff diameter of the impaction stage immediately upstream. The cutoff diameter is the diameter for which the collection efficiency of the given impaction stage would be 0.50. The cutoff diameters were taken from information supplied by the impactor manufacturer. Figure 9 shows four measurements of the inlet cumulative particle size distribution by mass of the iron oxide pigment (Mapico Black) as generated by the Acrison dust feeder. Figure 10 gives the same information for the fly ash aerosol. The cutoff diameters for the impactors were: 13.7, 8.6, 5.6, 4.0, 2.5, 1.3, 0.80, and 0.54 μm. Conditions such as humidity and feed rate would be expected to alter the size distributions somewhat for different tests. The efficiency tests measured the outlet concentration in a certain size interval versus the inlet concentration in that size

TEST NO

- 17 x - HEAVY GRAIN LOADING, AMBIENT TEMPERATURE
- 19 o - HEAVY GRAIN LOADING, ELEVATED TEMPERATURE
- 12 Δ - LIGHT GRAIN LOADING, AMBIENT TEMPERATURE
- 14 ▽ - LIGHT GRAIN LOADING, ELEVATED TEMPERATURE

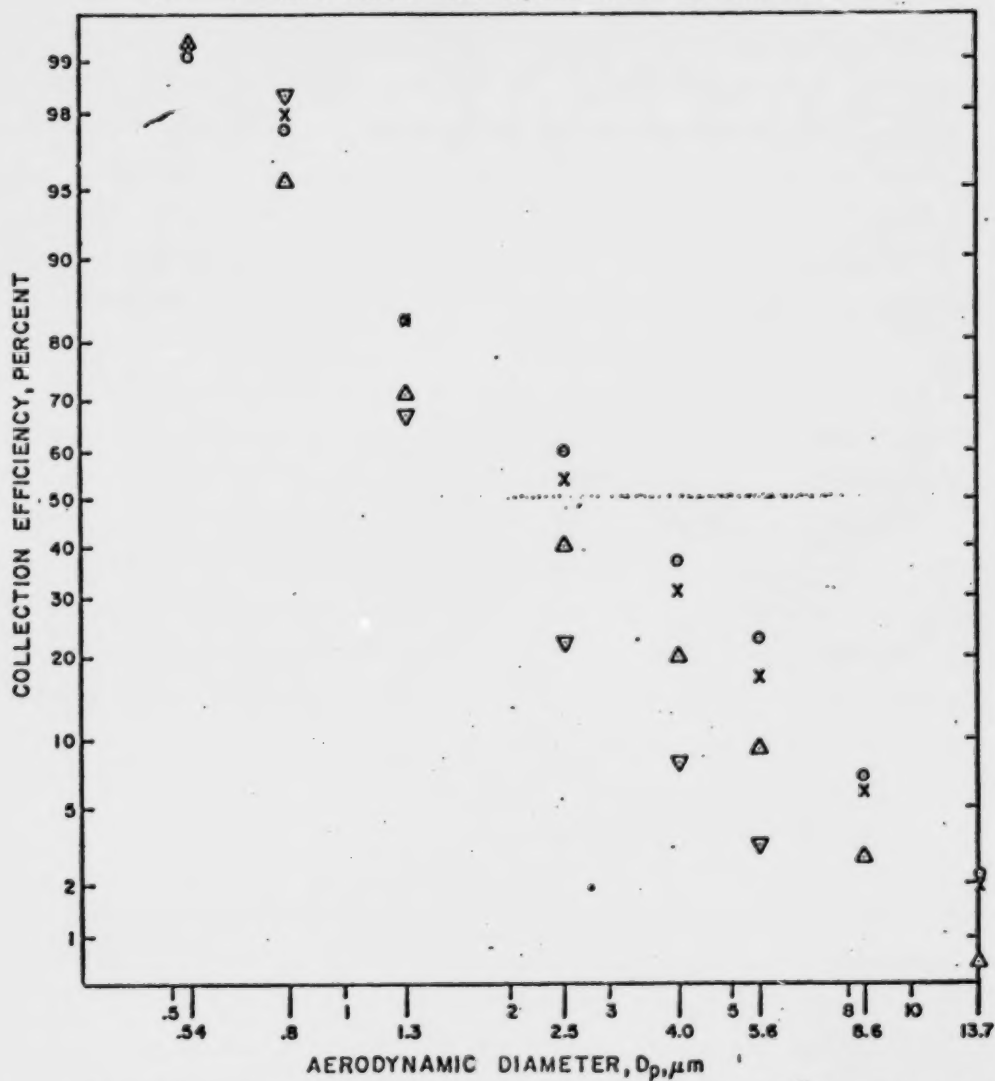


Figure 9. Inlet size distribution, iron oxide at $0.47 \text{ m}^3/\text{s}$ (1000 cfm)

interval, thus eliminating most of the effect of variations in inlet size distribution on collection efficiency. Outlet size distributions are shown in Figures 11 and 12.

Fractional Efficiency of Collection: Factorial Tests

A factorial test design was used to determine the Dynactor efficiency and the effects, if any, of flow rate, dust concentration, temperature, and dust type. Two levels of each of these parameters were used, which meant $2^4 = 16$ tests. Tables 5a and 5b give the levels of the parameters for both dusts and the number designating the test at each particular set of parameters. The data from these tests are in Appendix B. In Tables 5a and 5b the balanced factorial design test matrix is enclosed in a heavier line box. The design allowed testing whether or not each of the parameters was significant and whether or not interactions of two parameters were significant, using standard analysis of variance, and allowed estimates of the experimental error of measurement. The other tests done with iron oxide were made to investigate the efficiency of a single stage, the effect of a lower spray nozzle pressure, the effect of the addition at the inlet of water vapor, and the effect of addition of surfactant to the spray. Three measurements were made at one set of conditions to provide a second estimate of experimental variation. In all, 25 tests have been reported. The results of another seven were not reported because of various failures during the experiments, listed in Appendix B.

Statistical Analysis of Data

The data analysis was designed through a cooperative effort with GCA, University of Dayton Research Institute, and the Control Systems Laboratory at EPA. The computer program used to analyze the data was the BMD02V program from the Biomedical series, 1966 revision.⁷

TEST NO

- 21 x - HEAVY GRAIN LOADING, AMBIENT TEMPERATURE
- 22 o - HEAVY GRAIN LOADING, ELEVATED TEMPERATURE
- 9 Δ - LIGHT GRAIN LOADING, AMBIENT TEMPERATURE
- 10 ▽ - LIGHT GRAIN LOADING, ELEVATED TEMPERATURE

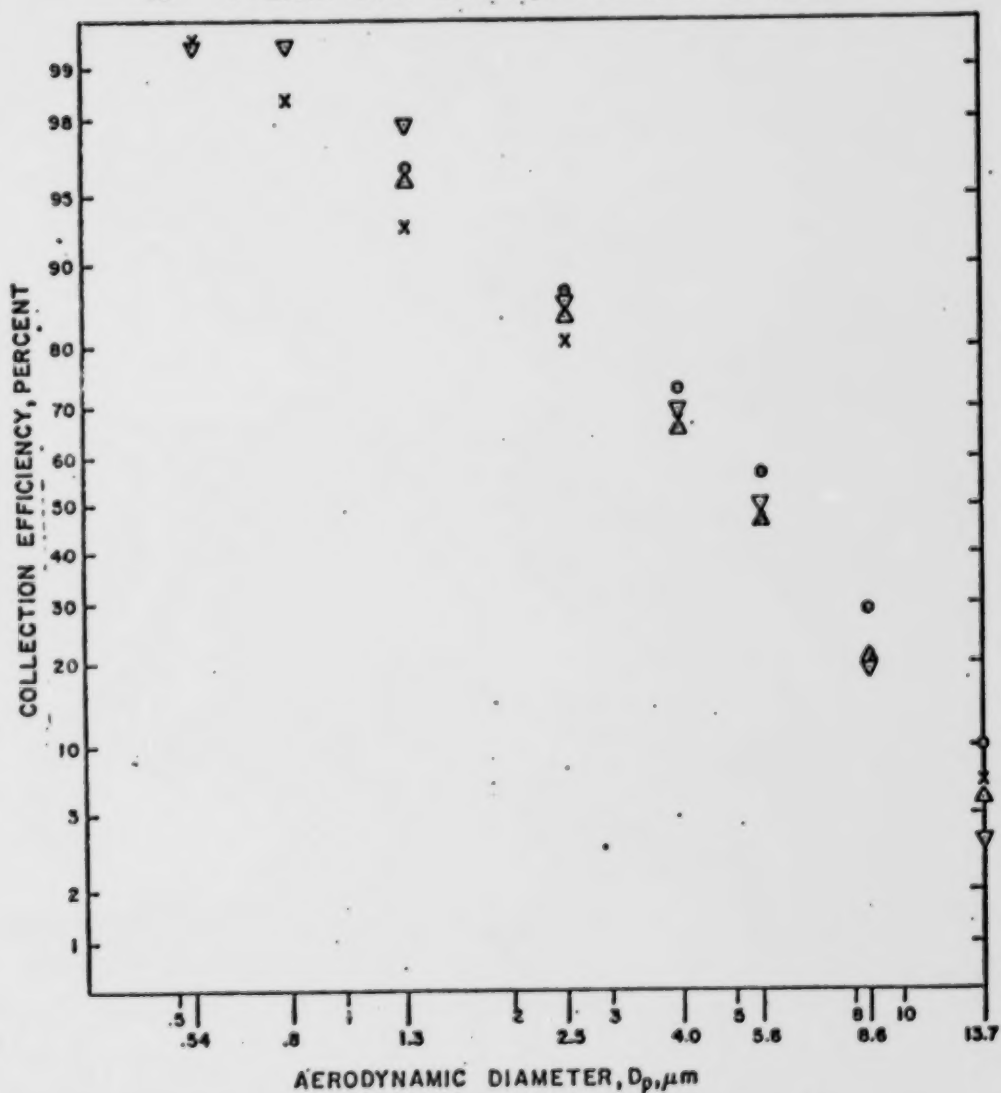


Figure 10. Inlet size distribution, fly ash at $0.47 \text{ m}^3/\text{s}$ (1000 cfm)

TEST NO.

- 17 x -HEAVY GRAIN LOADING, AMBIENT TEMPERATURE
- 19 o -HEAVY GRAIN LOADING, ELEVATED TEMPERATURE
- 12 Δ -LIGHT GRAIN LOADING, AMBIENT TEMPERATURE
- 14 ▽ -LIGHT GRAIN LOADING, ELEVATED TEMPERATURE

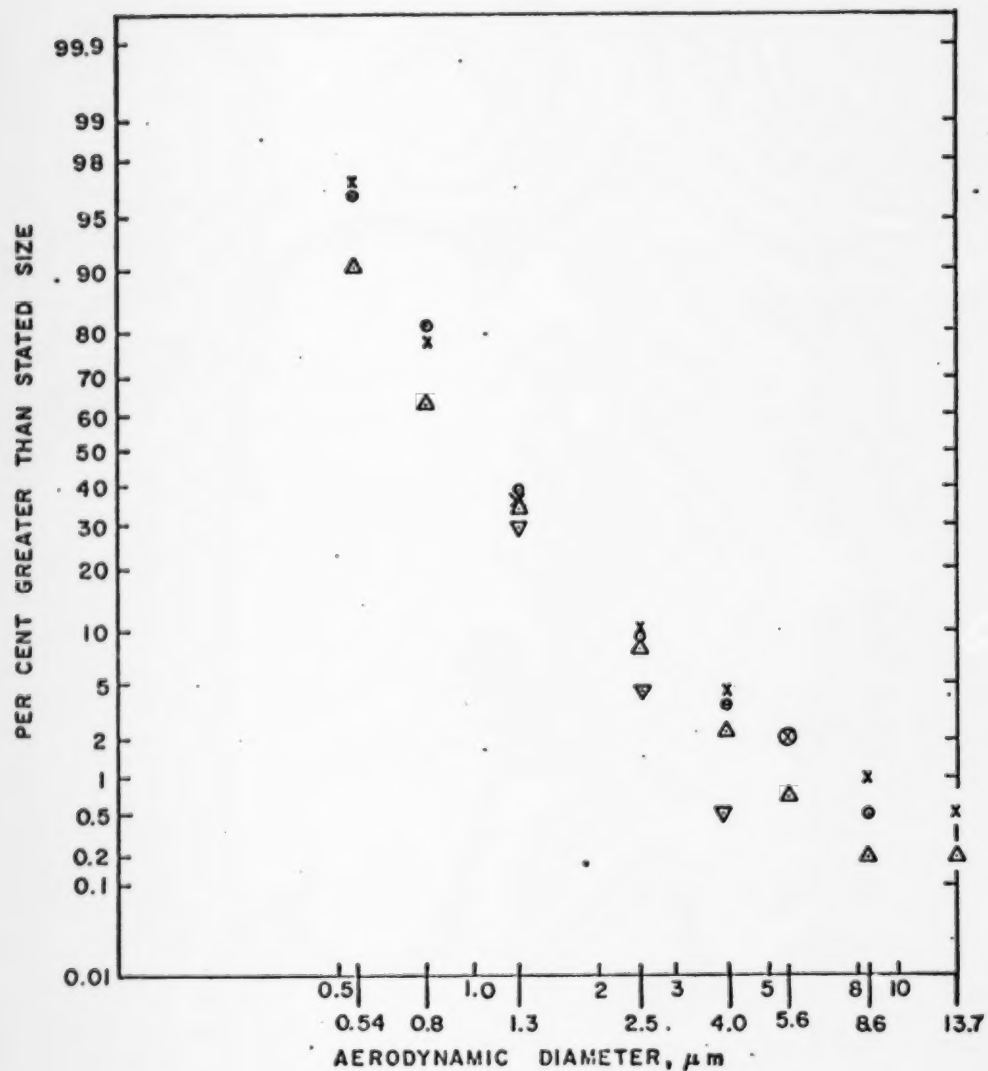


Figure 11. Outlet size distribution, iron oxide aerosol at $0.47 \text{ m}^3/\text{s}$ (1000 cfm)

TEST NO.

9	x	-LIGHT	GRAIN LOADING, AMBIENT TEMPERATURE
10	o	-LIGHT	GRAIN LOADING, ELEVATED TEMPERATURE
21	Δ	-HEAVY	GRAIN LOADING, AMBIENT TEMPERATURE
22	▽	-HEAVY	GRAIN LOADING, ELEVATED TEMPERATURE

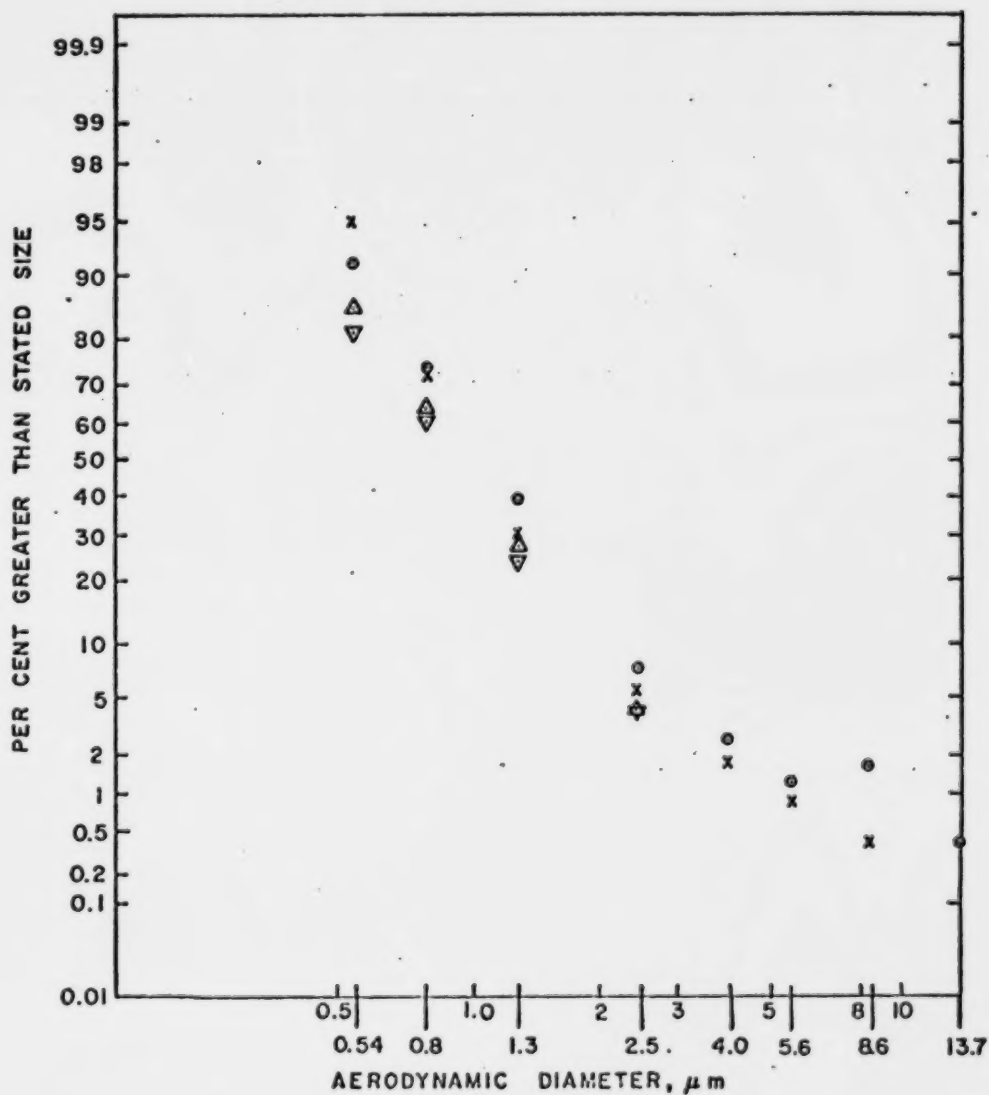


Figure 12. Outlet size distribution, fly ash at $0.47 \text{ m}^3/\text{s}$ (1000 cfm)

Table 5a. TEST MATRIX, FLY ASH AEROSOL

500 cfm (0.23 m ³ /s)		1000 cfm (0.47 m ³ /s)	
~ 1 gr/ft ³ (~ 1 g/m ³)		~ 1 gr/ft ³ (~ 1 g/m ³)	~ 0.1 gr/ft ³ (~ 0.1 g/m ³)
Heated ^a	#7	#27	#22
Ambient ^b	#8	#26	#21
			#10
			#9

^aInlet air T = 95°C = 200°F.^bInlet air T = 21°C = 70°F.

Table 5b. TEST MATRIX, IRON OXIDE AEROSOL

	500 cfm (0.23 m ³ /s)		1000 cfm (0.47 m ³ /s)		1500 cfm (0.71 m ³ /s)
	~ 1 gr/ft ³ (~ 1 g/m ³)	~ 0.1 gr/ft ³ (~ 0.1 g/m ³)	~ 1 gr/ft ³ (~ 1 g/m ³)	~ 0.1 gr/ft ³ (~ 0.1 g/m ³)	~ 1 gr/ft ³ (~ 1 g/m ³)
Heated ^a	#5	#24	#19	#14	#30
Ambient ^b	#4	#23	#16,17,18	#12	#29
First stage ^b				#32	
Steam added	#28, 31				
Surfactant ^b			#25		
Low spray pressure ^b				#13	

^aInlet air T = 95°C = 200°F^bInlet air T = 21°C = 70°F

The following were treated as independent variables for this analysis: total concentration (total filter), total impactor sample, impactor samples on each of stages 5, 6, 7, 8, and impactor final filter. The efficiencies of each of these seven aerosol size fractions were put through an analysis of variance, using the standard F-test.

The computer program calculated the following for each of the size fractions used:

- "grand mean" of all 16 tests
- "marginal means" of sets of eight tests having one or the other of the treatment parameters: dust types, flow rates, inlet concentrations, temperatures
- "sum of squares" due to each of the four treatment parameters as well as those due to two-factor and three-factor interactions between the parameters.

A decision had to be made whether to test for the four three-factor interactions and have only one estimate of the experimental error (the residual sum of squares) or to limit the tests to one- and two-factor analysis and have five estimates of the experimental error (the residual sum of squares and the four three-factor sums of squares). The latter choice was made, increasing the sensitivity of the tests for the one- and two-factor contributions. This meant that the appropriate F-test to use was an F-test distribution having one degree of freedom in the numerator and five in the denominator, $F(1,5)$.

The results of the factorial test are summarized in Table 6. The mean efficiencies for the tests and the corresponding uncertainties are listed with the aerosol fraction to which they correspond. The aerosol fractions are: (1) the size intervals between impactor cutoffs, (2) the total filter, (3) the sum of the material collected on the impactor; the last has somewhat smaller mean sizes than the total filter due to losses of the very largest particles in the drying sections.

The efficiencies for the two different dusts for the total filter and the total impactor have been presented separately because these would be expected to have very different median aerodynamic diameters, as seen from the size distributions shown in Figures 9 and 10. The uncertainty figures are derived from the uncertainty estimates for a single test, which will be explained below.

Table 6. SUMMARY OF RESULTS OF 16 COLLECTION
EFFICIENCY TESTS FOR DYNACTOR
(FACTORIAL TEST DESIGN)

Aerosol fraction	Mean efficiency	Number of tests, n	Estimated uncertainty ^a ($\pm \sigma_e / \sqrt{n}$)
Total filter	96.04 %	16	± 0.32 %
Iron oxide	93.11	8	0.46
Flyash	98.97	8	0.46
Total impactor	93.71	16	0.32
Iron oxide	89.81	8	0.45
Flyash	97.60	8	0.45
2.5 - 4.0 μm	98.37	16	0.12
1.3 - 2.5 μm	93.00	16	0.21
0.8 - 1.3 μm	75.4	16	2.1
0.54 - 0.8 μm	27.4	16	6.6
≤ 0.54 μm	47.4	16	3.7

^aFrom analysis of variance. See Table 10.

Tables 7a through 7g present a much more detailed picture of the results of the efficiency tests. Here are listed:

- The aerosol fraction
- The mean of all the efficiency tests in the factorial design
- The means of the eight tests each at two different levels of flow, temperature, and concentration, and two different dusts
- The results of the standard F-test analysis of variance, for an F ratio having a numerator of 1 degrees of freedom and a denominator of 5 degree of freedom
- The mean square error associated with one measurement at this size fraction.

The analysis of variance allows one to determine what likelihood there is that the differences noted between measurements come from differences in the parameters under study rather than from extraneous variations. The "significance level" is the probability that one would be correct in ascribing a difference in the results to a difference in the level of the parameter under test, here flow, dust, temperature, concentration, making the usual statistical assumptions about normal populations. Table 8 lists the significance levels for the effects of these parameters on efficiencies of collection for the various aerosol fractions.

The information in the Tables 7a through 7g, Table 8, and in Figures 13 and 14 allow us to draw the following conclusions:

1. The lower flow rate yielded higher efficiencies for all size fractions and the differences were usually statistically significant.
2. Fly ash was collected with greater efficiency than iron oxide for all size fractions, and these differences were usually statistically significant.
3. The lower temperature produced greater efficiencies than did the higher temperature in seven of eight aerosol fractions, but this was statistically significant in only two fractions.
4. Higher concentrations were collected with greater efficiency than lower concentrations and this was statistically significant in most fractions.

Table 7a. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Total Filter

GRAND MEAN OF EFFICIENCY TESTS: 96.04

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m ³ /min (500 cfm)	96.69
	28.3 m ³ /min (1000 cfm)	95.40
DUST	IRON OXIDE	93.11
	FLY ASH	98.97
TEMPERATURE	~ 20°C (~ 70°F)	96.50
	~ 95°C (~ 200°F)	95.59
CONCENTRATION	~ 0.2 g/m ³ (0.1 gr/ft ³)	94.87
	~ 2.0 g/m ³ (1.0 gr/ft ³)	97.21

RESULTS OF F-TEST ANALYSIS OF VARIANCE		
EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	3.95	-
(2) Dust	81.99	> .99
(3) Temperature	1.99	-
(4) Concentration	13.04	> .95
(2)(4)	11.93	> .95
(1)(4)	1.98	-
MEAN SQUARE ERROR: 1.677		

Table 7b. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Total Impactor

GRAND MEAN OF EFFICIENCY TESTS: 93.71

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m ³ /min (500 cfm)	94.05
	28.3 m ³ /min (1000 cfm)	93.36
DUST	IRON OXIDE	89.81
	FLY ASH	97.60
TEMPERATURE	~ 20°C (~ 70°F)	94.40
	~ 95°C (~ 200°F)	93.01
CONCENTRATION	~ 0.2 g/m ³ (0.1 gr/ft ³)	91.62
	~ 2.0 g/m ³ (1.0 gr/ft ³)	95.79

RESULTS OF F-TEST ANALYSIS OF VARIANCE		
EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	1.19	-
(2) Dust	152.6	> .99
(3) Temperature	4.83	> .90
(4) Concentration	43.50	> .99
(2)(4)	24.33	> .99
(1)(3)	6.33	> .90
MEAN SQUARE ERROR: 1.593		

Table 7c. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Impactor Stage #5 , 2.5 - 4.0 μm

GRAND MEAN OF EFFICIENCY TESTS: 98.37

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m^3/min (500 cfm)	98.75
	28.3 m^3/min (1000 cfm)	97.99
DUST	IRON OXIDE	97.47
	FLY ASH	99.26
TEMPERATURE	$\sim 20^\circ\text{C}$ ($\sim 70^\circ\text{F}$)	98.57
	$\sim 95^\circ\text{C}$ ($\sim 200^\circ\text{F}$)	98.16
CONCENTRATION	$\sim 0.2 \text{ g}/\text{m}^3$ (0.1 gr/ft ³)	98.00
	$\sim 2.0 \text{ g}/\text{m}^3$ (1.0 gr/ft ³)	98.74

RESULTS OF F-TEST ANALYSIS OF VARIANCE

EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	10.50	> .95
(2) Dust	57.83	> .99
(3) Temperature	3.08	-
(4) Concentration	9.86	> .95
(2)(4)	20.45	> .99
(3)(4)	3.43	-
(2)(3)	2.71	-
MEAN SQUARE ERROR: 0.221		

Table 7d. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Impactor stage #6, 1.3 - 2.5 μm

GRAND MEAN OF EFFICIENCY TESTS: 93.00

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m ³ /min (500 cfm)	94.82
	28.3 m ³ /min (1000 cfm)	91.17
DUST	IRON OXIDE	92.37
	FLY ASH	93.62
TEMPERATURE	~ 20°C (~ 70°F)	93.54
	~ 95°C (~ 200°F)	92.46
CONCENTRATION	~ 0.2 g/m ³ (0.1 gr/ft ³)	92.59
	~ 2.0 g/m ³ (1.0 gr/ft ³)	93.41

RESULTS OF F-TEST ANALYSIS OF VARIANCE		
EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	75.80	> .99
(2) Dust	8.89	> .95
(3) Temperature	6.57	> .95
(4) Concentration	3.86	-
(2)(4)	40.71	> .99
(1)(4)	25.69	> .99
(1)(3)	11.55	> .95
(1)(2)	8.19	> .95
MEAN SQUARE ERROR: 0.703		

Table 7e. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Impactor stage #7, 0.8 - 1.3 μm

GRAND MEAN OF EFFICIENCY TESTS: 75.44

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m ³ /min (500 cfm)	83.45
	28.3 m ³ /min (1000 cfm)	67.44
DUST	IRON OXIDE	81.87
	FLY ASH	69.01
TEMPERATURE	~ 20°C (~ 70°F)	78.95
	~ 95°C (~ 200°F)	71.94
CONCENTRATION	~ 0.2 g/m ³ (0.1 gr/ft ³)	72.79
	~ 2.0 g/m ³ (1.0 gr/ft ³)	78.10

RESULTS OF F-TEST ANALYSIS OF VARIANCE		
EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	3.79	-
(2) Dust	2.45	-
(3) Temperature	0.73	-
(4) Concentration	0.42	-
(1)(2)	2.45	-
(1)(3)	1.63	-
MEAN SQUARE ERROR: 270.6		

Table 7f. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Impactor stage #8 , 0.54 - 0.8 μm

GRAND MEAN OF EFFICIENCY TESTS: 27.39

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m ³ /min (500 cfm)	26.66
	28.3 m ³ /min (1000 cfm)	28.12
DUST	IRON OXIDE	16.92
	FLY ASH	37.86
TEMPERATURE	~ 20°C (~ 70°F)	25.04
	~ 95°C (~ 200°F)	29.75
CONCENTRATION	~ 0.2 g/m ³ (0.1 gr/ft ³)	26.51
	~ 2.0 g/m ³ (1.0 gr/ft ³)	28.27

RESULTS OF F-TEST ANALYSIS OF VARIANCE		
EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	0.01	-
(2) Dust	2.50	-
(3) Temperature	.13	-
(4) Concentration	.02	-
(1)(3)	2.22	-
MEAN SQUARE ERROR: 700.9		

Table 7g. RESULTS OF STATISTICAL ANALYSIS ON EFFICIENCY

PARTICLE SIZE FRACTION: Final filter after impactor, $\leq 0.54 \mu\text{m}$

GRAND MEAN OF EFFICIENCY TESTS: 47.38

MARGINAL MEANS PARAMETER	LEVEL	MEAN
FLOW	14.2 m ³ /min (500 cfm)	49.26
	28.3 m ³ /min (1000 cfm)	45.50
DUST	IRON OXIDE	39.94
	FLY ASH	54.82
TEMPERATURE	~ 20°C (~ 70°F)	51.36
	~ 95°C (~ 200°F)	43.40
CONCENTRATION	~ 0.2 g/m ³ (0.1 gr/ft ³)	23.51
	~ 2.0 g/m ³ (1.0 gr/ft ³)	71.25

RESULTS OF F-TEST ANALYSIS OF VARIANCE		
EFFECT	F (1,5)	SIGNIFICANCE LEVEL (IF ≥ 0.90)
(1) Flow	0.26	-
(2) Dust	4.05	.90
(3) Temperature	1.16	-
(4) Concentration	41.62	> .99
(2)(4)	7.04	> .95
(1)(4)	4.60	> .90
(1)(3)	1.83	-
MEAN SQUARE ERROR: 219.0		

Table 8. SIGNIFICANCE OF EFFECTS OF FLOW, DUST, TEMPERATURE, AND CONCENTRATION ON SCRUBBER COLLECTION EFFICIENCY

Aerosol fraction	Significance level			
	Flow	Dust	Temp.	Conc.
Total filter	~ 0.90	> 0.99	--	> 0.95
Total impactor	--	> 0.99	> 0.99	> 0.99
2.5 - 4.0 μm	> 0.95	> 0.99	--	> 0.95
1.3 - 2.5 μm	> 0.99	> 0.95	> 0.95	~ 0.90
0.8 - 1.3 μm	~ 0.90	--	--	--
0.54 - 0.8 μm	--	--	--	--
$\leq 0.54 \mu\text{m}$	--	~ 0.90	--	> 0.99

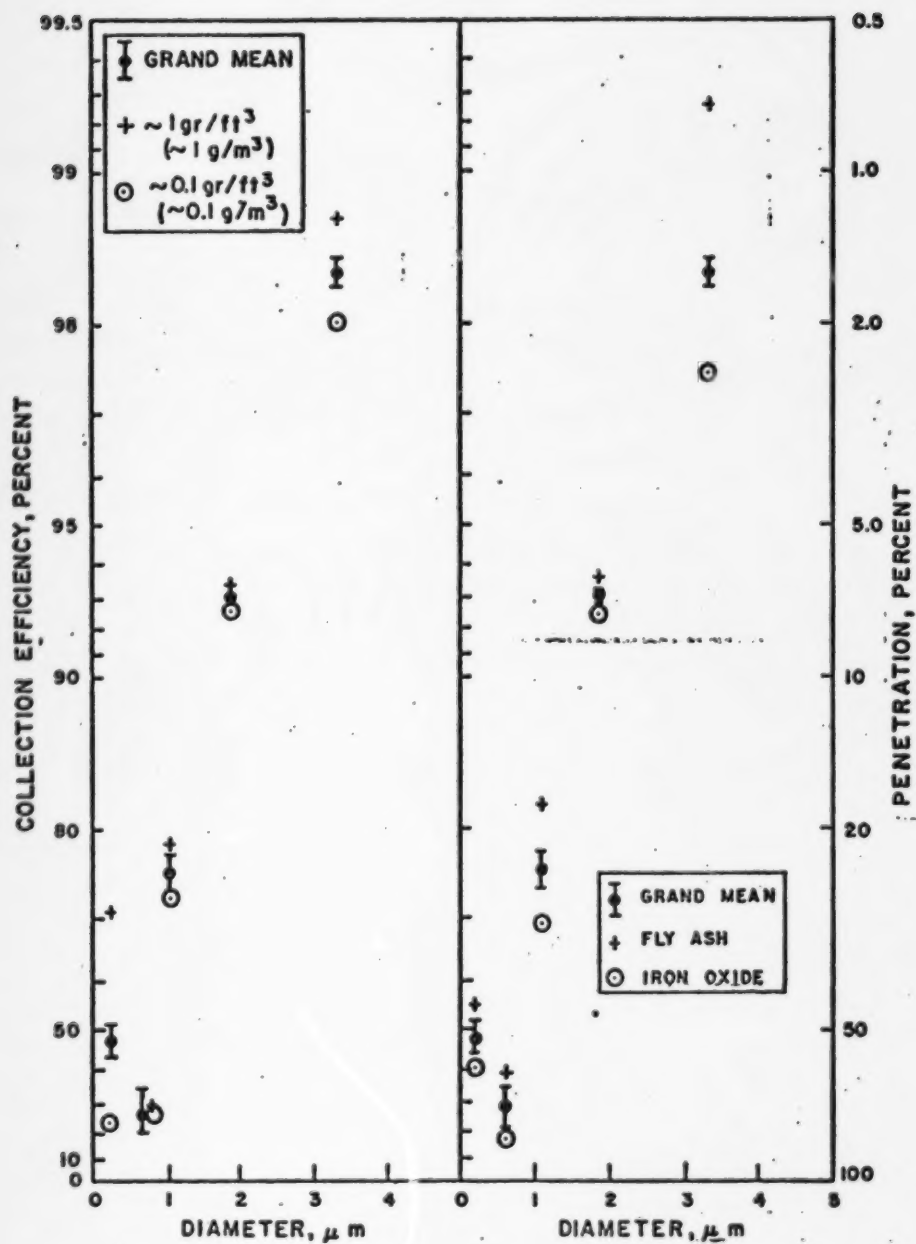


Figure 13. Dynactor scrubber collection efficiency versus particle aerodynamic diameter, effects of loading and dust type

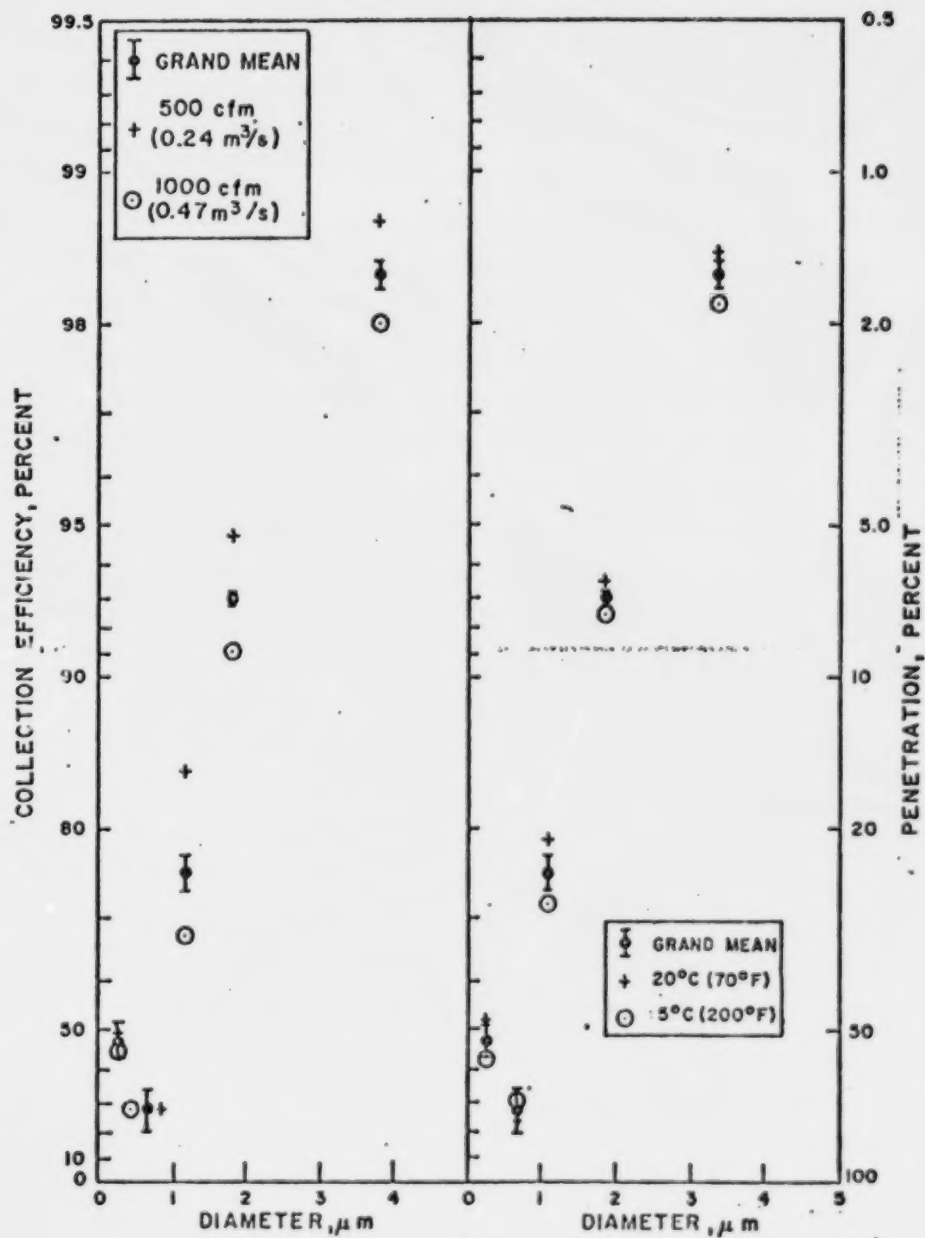


Figure 14. Dynactor scrubber collection efficiency versus particle aerodynamic diameter, effects of flow rate and inlet temperature

The F-test analysis of variance also gave information on the significance of interactions between the variables flow (1), dust (2), temperature (3) and concentration (4). Thus the interaction labeled (2) (4) in the Tables 7a, b, c, d, g, is the interaction of dust and concentration, which can be interpreted in either of two ways: the degree to which different dusts gave a different dependence of efficiency upon concentration or the degree to which different concentrations gave a different dependence of efficiency upon dust type. In Table 9 are arrayed the averages of four tests each at the particular combinations of parameters whose interaction was found to be significant for the 1.3 to 2.5 μm aerosol fraction, Table 7d. Thus, the first group contains two levels of concentration and two types of dust, from which we see that the difference in efficiency between high and low concentrations was more pronounced for iron oxide than it was for flyash. The next set in Table 9 shows that the difference in efficiency between the two types of dust was greater at the lower flow rate than at the higher. Similar interpretations would be appropriate for the other two sets of data in Table 9: the effect of temperature was greater at the higher flow rate and the effect of concentration was greater at the lower flow rate. The F-test values in Table 7d indicate all these statements are statistically significant. The flow interactions are displayed in Figure 15. The explanations of all these interactions for all the stages would be difficult to make; an example of one such explanation would be that the difference in efficiency for the two dusts is caused by collection mechanisms, such as diffusion or electrostatics, that increase with increased residence time, thus producing a greater difference between dusts at the lower flow rate.

Estimates of Experimental Error

Two methods were used to get estimates of the experimental error. The first involved dividing the residual sum of squares by the number of degrees of freedom (5) and taking the square root, for the data in the balanced 2^4 test matrix used in the analysis of variance. This is a

Table 9. DETAILED ANALYSIS OF INTERACTIONS FOR DYNACTOR
EFFICIENCY ON 1.3 - 2.5 μm AEROSOL FRACTION
(STAGE #6)

Efficiencies (N=4)	Parameter: Dust (2)	
	Iron oxide	Fly ash
Concentration (4)		
~ 0.1 g/m ³	90.6	94.6
~ 1.0 g/m ³	94.2	92.7
Dust (2)	Parameter: Flow (1)	
	500 cfm	1000 cfm
	Iron oxide	91.2
	Fly ash	91.2
Temperature (3)		
20°C	94.6	92.4
95°C	95.0	89.9
Concentration (4)		
~ 0.1 g/m ³	93.4	91.8
~ 1.0 g/m ³	96.3	90.6

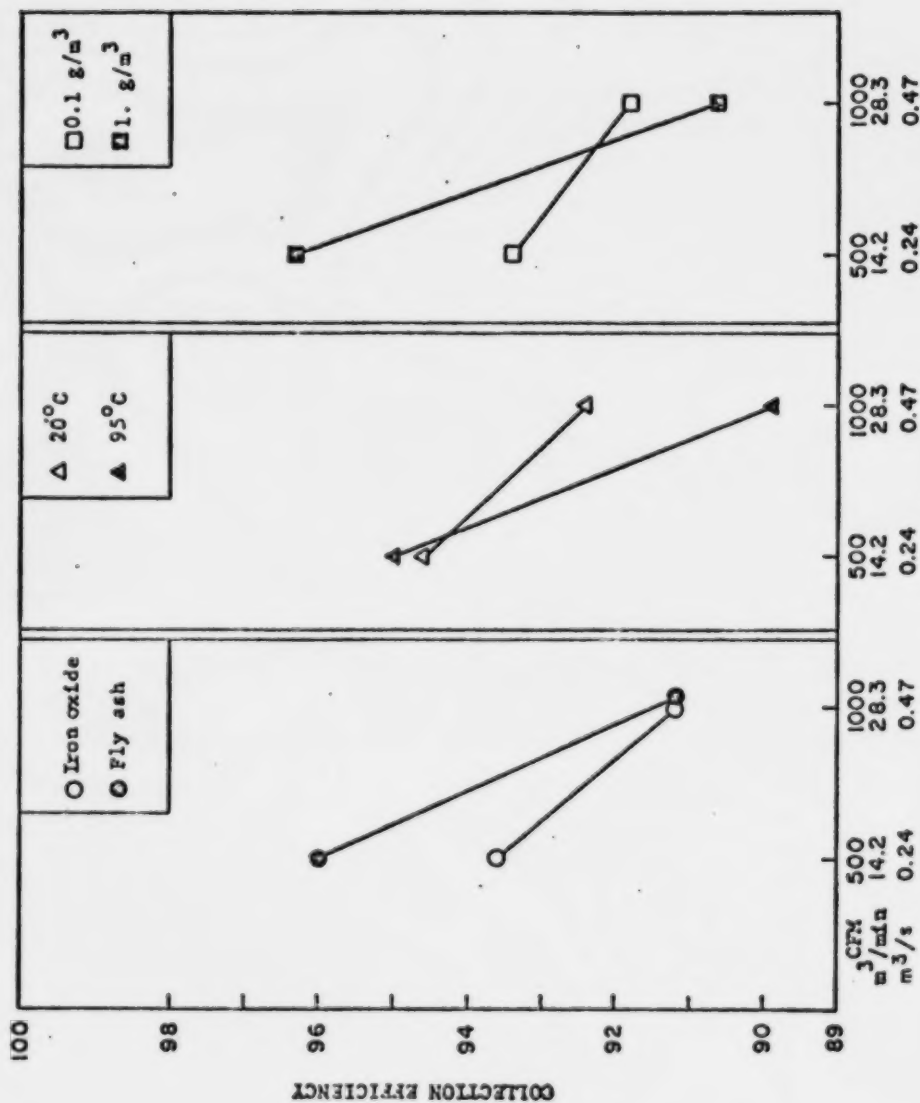


Figure 15. Collection efficiency, 1.3-2.5 μ m, versus flow for different dusts, temperatures, and concentrations

standard method. The residuals were those from the analysis of the individual factors (flow, dust, temperature, and concentration) and two-factor interactions. Such residuals would include three-factor interactions, if any, and mistakenly treat them as experimental error. (Nearly always, these three-factor contributions to the sum of squares were of the same magnitude as the residuals left even after the three-factor interactions were taken into account.) The second estimate of the experimental error came from the three replications for iron oxide at 1000 cfm ($0.47 \text{ m}^3/\text{s}$), $\sim 1 \text{ gr/ft}^3$ ($\sim 1 \text{ g/m}^3$), at ambient temperature. Both are given in Table 10. In five of seven cases, the estimates from the replication tests were lower. The standard deviation of an average of N such tests would be the standard deviation for one test divided by $N^{1/2}$. For any one of the measurements to be significantly different from a given value, it should be at least two standard deviations different from that value, which gives a guideline for comparing the results of the tests done outside the factorial design test matrix.

Collection Efficiency Tests at 1500 cfm ($0.71 \text{ m}^3/\text{s}$)

An 8-point pitot tube traverse was used downstream in 8-inch (0.20 m) diameter duct and yielded an outlet flow of 1510 cfm ($0.71 \text{ m}^3/\text{s}$). A 20-point pitot tube traverse used upstream in 12-inch (0.30 m) diameter duct yielded an inlet flow of 1250 cfm ($0.59 \text{ m}^3/\text{s}$). Magnetic gauges used for the above traverses were checked with an upright manometer. They were in good agreement which determined that the gauges were not the cause of the above flow discrepancy.

An attempt was made to seal leaks in the Dynactor and peripheral ducting, but it must be assumed that with a static pressure loss greater than 2.0" H_2O (5.0 cm WC) at the outlet some leakage occurred. Flow through the Dynactor was calculated as the average between inlet and outlet volumes, but grain loading was calculated on the basis of the flows measured upstream and downstream. Efficiency was determined by the

ratio of the rate of particulate mass flow out of the Dynactor to the rate of particulate mass flow into the Dynactor.

Table 10. ESTIMATES OF EXPERIMENTAL ERROR FOR SINGLE TEST FROM THE RESIDUALS OF THE SUM OF SQUARES AND FROM THE REPLICATION TESTS, Nos. 16, 17, 18

Aerosol fraction	Standard deviation estimates	
	(M.S.E.) ^{1/2} ^a (%)	0.59 x range ^b (%)
Total filter	1.29	0.41
Total impactor	1.26	1.00
2.5 - 5.6 μm	0.47	0.59
1.3 - 2.5 μm	0.84	0.12
0.8 - 1.3 μm	8.4 (17.7) ^c	3.7
0.54 - 0.8 μm	26.5	34.0
$\leq 0.54 \mu\text{m}$	14.8	11.2

^aRoot mean square of residual sum of squares after two-factor analysis of factorial design tests.

^bBest estimate of standard deviation from range of three measurements.¹³

^cValue including a discarded datum, test No. 10 (12.5).

The results for the tests at 1500 cfm ($0.71 \text{ m}^3/\text{s}$) and at 1000 cfm ($0.47 \text{ m}^3/\text{s}$) for iron oxide at $1 \text{ mg}/\text{m}^3$ are given in Table 11 to facilitate comparison. At ambient temperature, the lower flow rate produced a higher efficiency in six of the eight aerosol fractions measured and indistinguishable efficiencies in one, diameters $\leq 0.54 \mu\text{m}$. In three cases (total impactor, 2.5 to $4.0 \mu\text{m}$, 1.3 to $2.5 \mu\text{m}$) the higher flow rate value was more than two of its estimated standard deviations away from the low flow rate mean, which would support the conclusion that at ambient temperature the effect of increasing the flow lowered the efficiency. At the elevated temperature, 95°C (200°F),

raising the flow seems not to have decreased the efficiency. Three efficiencies were lower and three were higher. The data from the tests at 1000 cfm ($0.47 \text{ m}^3/\text{s}$) and 1500 cfm ($0.71 \text{ m}^3/\text{s}$) displayed lower efficiencies for increased flow at 20°C but not at 95°C ; at 1000 cfm ($0.47 \text{ m}^3/\text{s}$), six of six fractions showed higher efficiencies at 21°C than at 95°C , but at 1500 cfm ($0.71 \text{ m}^3/\text{s}$) six of seven fractions showed higher efficiencies at 95°C than at 21°C , suggesting an interaction between the two variables.

Table 11. RESULTS OF DYNACTOR COLLECTION EFFICIENCY TESTS UNDER SIMILAR CONDITIONS EXCEPT FOR FLOW RATE (IRON OXIDE, $\sim 1 \text{ g}/\text{m}^3$)

Aerosol fraction	21°C (70°F)		95°C (200°F)	
	1500 cfm ($0.71 \text{ m}^3/\text{s}$)	1000 cfm ($0.47 \text{ m}^3/\text{s}$)	1500 cfm ($0.71 \text{ m}^3/\text{s}$)	1000 cfm ($0.47 \text{ m}^3/\text{s}$)
Total filter	94.8	95.4	94.7	94.9
Total impactor	88.9	93.9	93.8	91.7
2.5 - 4.0 μm	97.0	98.5	98.6	97.6
1.3 - 2.5 μm	87.1	93.1	89.4	89.9
0.8 - 1.3 μm	75.0	83.7	83.1	75.9
0.54 - 0.8 μm	≤ 19.4	46.4	75.8	--
$\leq 0.54 \mu\text{m}$	--	≤ 82.5	--	66.1
Test number	29	16,17,18 avg.	30	19

Collection Efficiency Tests With Inlet Air Humidified

Efficiency tests were performed using heated air to evaporate a fine water spray upstream from the Dynactor inlet to use the subsequent condensation of water vapor to enhance particle collection (diffusiophoresis). The spray was introduced downstream from the inlet sampling probes. Two # 1511 Sprayco pinjet nozzles operated at 80 psi ($5.3 \times 10^3 \text{ cm WC}$) were used, spraying 0.56 gal/min ($3.5 \times 10^{-5} \text{ m}^3/\text{s}$) into air at 350°F (117°C).

The humidity ratio was determined two ways: by weight change of desiccant material after the gas passed through a cyclone (10 mm) and by wet bulb/dry bulb thermometer measurements (and comparison with a psychometric chart). During test #28, the wet and dry bulb thermometers were inserted into the duct immediately upstream from the Dynactor inlet. During test #31 the gas sample was made to pass not only through a cyclone but also through a heating section into which the wet bulb and dry bulb thermometers were placed, and from which it passed into the desiccant. The ratio, by weight, of water vapor to dry air for test #28 was 0.032 as determined by desiccant weight gain and 0.057 as determined by the thermometric measurements. Some of this discrepancy was thought to be due to condensation in the sampling line to the desiccant, one of the reasons the heated section was introduced for test #31. For test #31, the humidity ratio was 0.070 as determined by the desiccant and 0.071 and 0.086 as determined by thermometric measurements near the beginning and end of the test. No intentional changes were made in the system in producing the high humidity ratio the second time, so the different average humidity ratios (0.044, 0.076) are rather puzzling.

The data from these two tests are given in Table 12, along with data from two tests most nearly matching the conditions of the steam addition tests. In each aerosol size fraction the ranges of the steam added tests and the tests without added steam overlap, with the exception of the diameter interval 1.3 to 2.5 μm , for which the efficiencies without steam addition are higher than those with added steam. The addition of water vapor to achieve an inlet humidity ratio of about 0.05 g water per g dry air did not appreciably enhance collection efficiency, an unexpected result.

Table 12. RESULTS OF DYNACTOR COLLECTION EFFICIENCY TESTS UNDER SIMILAR CONDITIONS BUT WITH AND WITHOUT STEAM ADDITION (IRON OXIDE, 500 cfm = 0.24 m³/s, LOADING ~ 1 g/m³)

Aerosol fraction	Tests					
	No steam			Steam added		
	#4	#5 ^a	Avg.	#28	#31	Avg.
Total filter	96.4	91.1	93.8	--	96.2	96.2
Total impactor	93.9	94.3	94.1	95.4	93.0	94.2
2.5 - 5.6 μm	98.3	99.1	98.7	99.3	98.9	99.1
1.3 - 2.5 μm	96.0	97.5	96.8	95.0	94.0	94.5
0.8 - 1.3 μm	85.2	89.3	87.2	85.7	80.3	83.0
0.54 - 0.8 μm	--	--	--	48.4	70.0	59.2
≤ 0.54 μm	73.3	72.0	72.6	≤ 64.4	≤ 80.0	≤ 72.2

^aThis test done at 95°C (= 200°F).

Collection Efficiency Test With Surfactant Added to the Spray

The addition of a surfactant chemical to the spray used in the Dynactor might be expected to affect efficiency by changing the droplet size distribution in the spray somewhat and changing the wetting efficacy of the droplets, both changes due to the lowering of the surface tension of the water in the spray. A surfactant was added to the water reservoir in the Dynactor's stages to form a 10 parts per million solution. An efficiency test (test #15) was run using this solution, but otherwise at the conditions at which the replicative tests (#17, 18, 16) were run; that is, 1000 cfm (0.47 m³/s), ~ 1 gr/ft³ (~ 1 g/m³), iron oxide aerosol, ambient temperature. Table 13 contains the efficiencies from the two types of test. In six of six aerosol fractions, the surfactant additive gave a higher efficiency than had been obtained without it, and in the other fraction there was no distinguishable difference. In the range 1.3 to 4.0 μm, the efficiencies were more than one standard deviation apart but less than two.

Table 13. RESULTS OF DYNACTOR COLLECTION EFFICIENCY TESTS UNDER SIMILAR CONDITIONS EXCEPT FOR THE ADDITION OF 10 ppm SURFACTANT TO THE SPRAY WATER

Aerosol fraction	Collection efficiencies	
	Surfactant added	No surfactant
Total filter	95.5	95.4
Total impactor	94.4	93.9
2.5 - 4.0 μm	99.2	98.5
1.3 - 2.5 μm	94.2	93.1
0.8 - 1.3 μm	84.9	83.7
0.54 - 0.8 μm	62.2	46.4
$\leq 0.54 \mu\text{m}$	≤ 82.2	≤ 82.2
Test number	25	16,17,18 avg.

Collection Efficiency Tests At Reduced Nozzle Pressure

One efficiency test was made using the Dynactor spray nozzles at 100 psig (7.04×10^2 cm WC), half their normal pressure. This test, #13 listed in Appendix B, is directly comparable with test #12, also listed in Appendix B, and in every size fraction it gave a lower efficiency. The total efficiency on iron oxide at 1000 cfm ($0.47 \text{ m}^3/\text{s}$) at $\sim 0.1 \text{ g/m}^3$ ($\sim 0.1 \text{ gr/ft}^3$) at ambient temperature was 81.8 percent for this reduced pressure, compared with 90.0 percent at the usual nozzle pressure for these same conditions.

Some of these results are discussed more fully in the next section, which also contains a comparison between the Dynactor scrubber and conventional venturi scrubber technology.

SECTION VI

DISCUSSION

In this section, we compare the Dynactor Scrubber with other scrubbers with respect to power consumption. The effects of the factors studied with the factorial design tests are discussed as well.

DYNACTOR SCRUBBER POWER CONSUMPTION COMPARISON

The prime function of the Dynactor scrubber is the same as that of the venturi scrubber, to remove particulate material, so the comparison between the two devices should be made for conditions under which they have the same, or nearly the same, efficiency. Both devices use water sprays to remove particulates. Both consume clean water. Both use power to produce a velocity difference between the sprays and the gas to be cleaned. Both would be expected to have similar waste disposal and maintenance costs.

The number used to specify efficiency is the "aerodynamic cut diameter," the particle aerodynamic diameter for which the device has a collection efficiency of 50 percent. (Note that this assumes the collection efficiency versus particle aerodynamic diameter is single-valued at 50 percent efficiency.) The cut diameter has long been used regarding impactors. The particle aerodynamic diameter is the diameter of a sphere with unit density (1 gm/cm^3) which would have the same terminal gravitational settling velocity in air as the particle. In the particle size range above a few tenths microns, impaction is the predominant scrubbing mechanism generally, so that in this particle size domain

the use of the aerodynamic cut diameter is reasonable. Calvert³ recently discussed its application vis a vis scrubber efficiencies.

The analysis proceeds as follows:

1. A curve for efficiency versus particle size is graphed from experimental data.
2. The particle aerodynamic diameter corresponding to 50 percent efficiency is determined from that curve; this is the aerodynamic cut diameter.
3. From the experimental conditions, the intrinsic power consumption is determined (flow times pressure drop for the motive fluid) and put in the form of power per volume flow of gas (=pressure), such as hp/1000 cfm or inches H₂O or cm H₂O (=cm WC).
4. The aerodynamic cut diameter is plotted against pressure drop or power per unit volume flow of gas on a graph (after Calvert)³ having predicted values for a venturi scrubber and other types of scrubbers.
5. From this plot one can determine whether more or less power is used by the scrubber in question than is predicted for other scrubbers at the same aerodynamic cut diameters.

Figures 16 to 20 present collection efficiency versus particle aerodynamic diameter for the two aerosols at the three flow rates. The efficiencies for the two smallest size intervals (points plotted at 0.27 μ m and 0.67 μ m) were determined as they had been for the statistical tests. The other efficiencies were obtained as follows: The impactor substrates had shown a weight loss generally 0.3 mg or less and the weighing uncertainty was about 0.1 mg, so that a best case efficiency value for any particle size fraction in any run was obtained by adding 0.4 mg to the net weights on the inlet impactor stages and subtracting 0.1 mg from the net weights on the outlet stages. The new weights were used to obtain concentrations, thus efficiencies. A worst case efficiency was obtained by reversing the treatments of the inlet and outlet impactor stages. (This would have been done for the two smallest size fractions but for

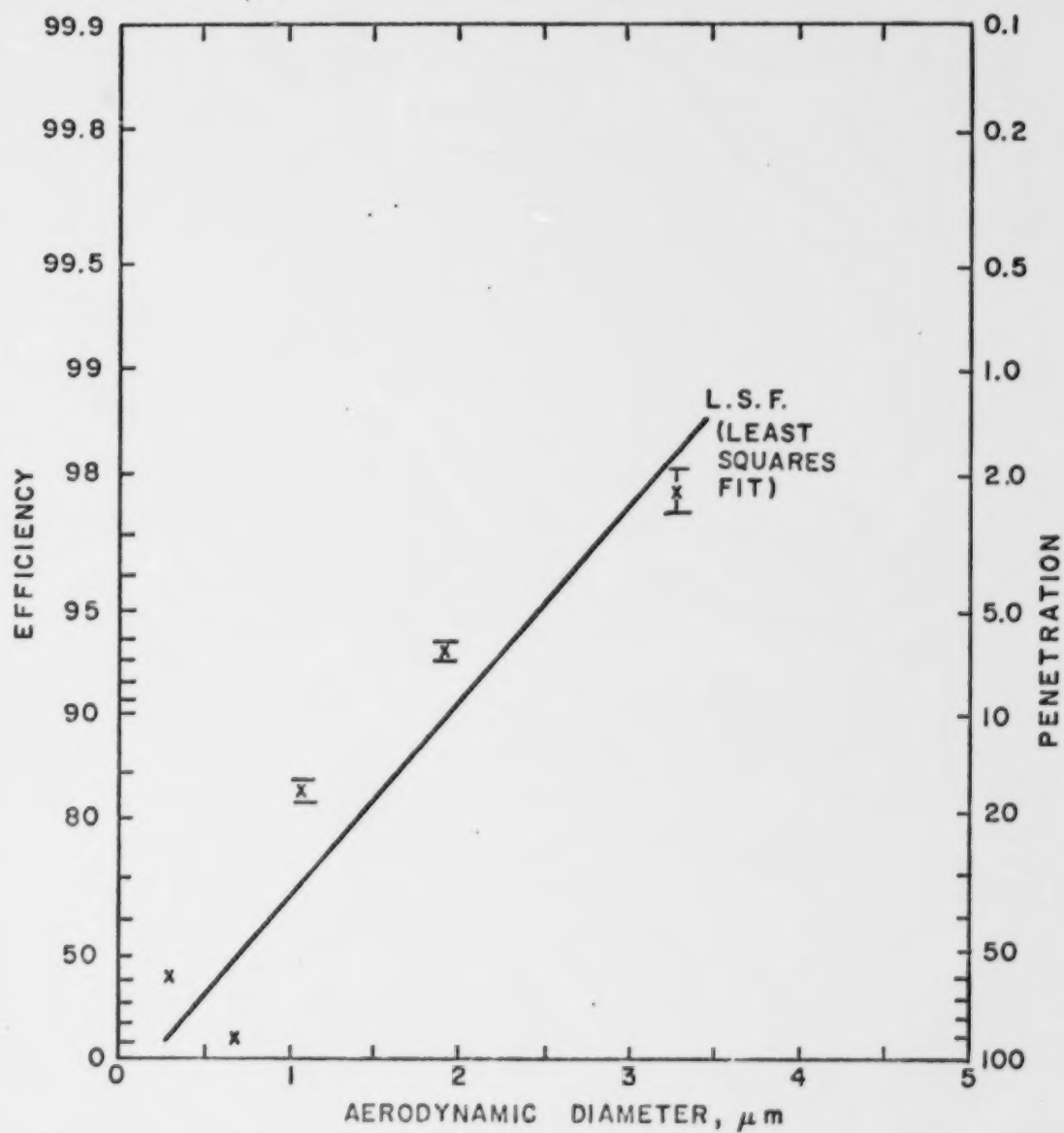


Figure 16. Dynactor collection efficiency versus aerodynamic diameter, average of data for iron oxide at $0.23 \text{ m}^3/\text{s}$ (500 cfm)

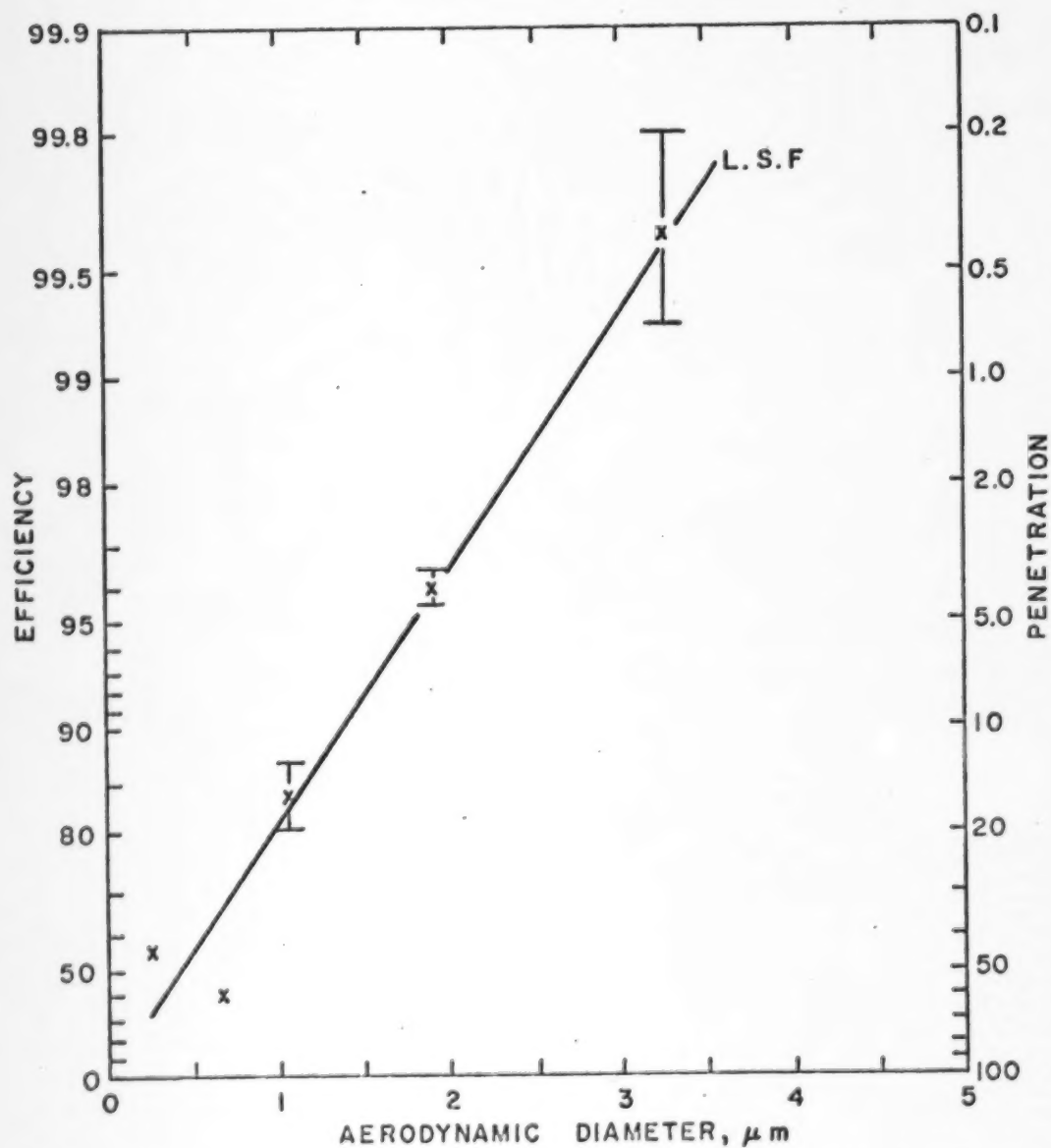


Figure 17. Dynactor collection efficiency versus aerodynamic diameter, averages of data for fly ash at $0.23 \text{ m}^3/\text{s}$ (500 cfm)

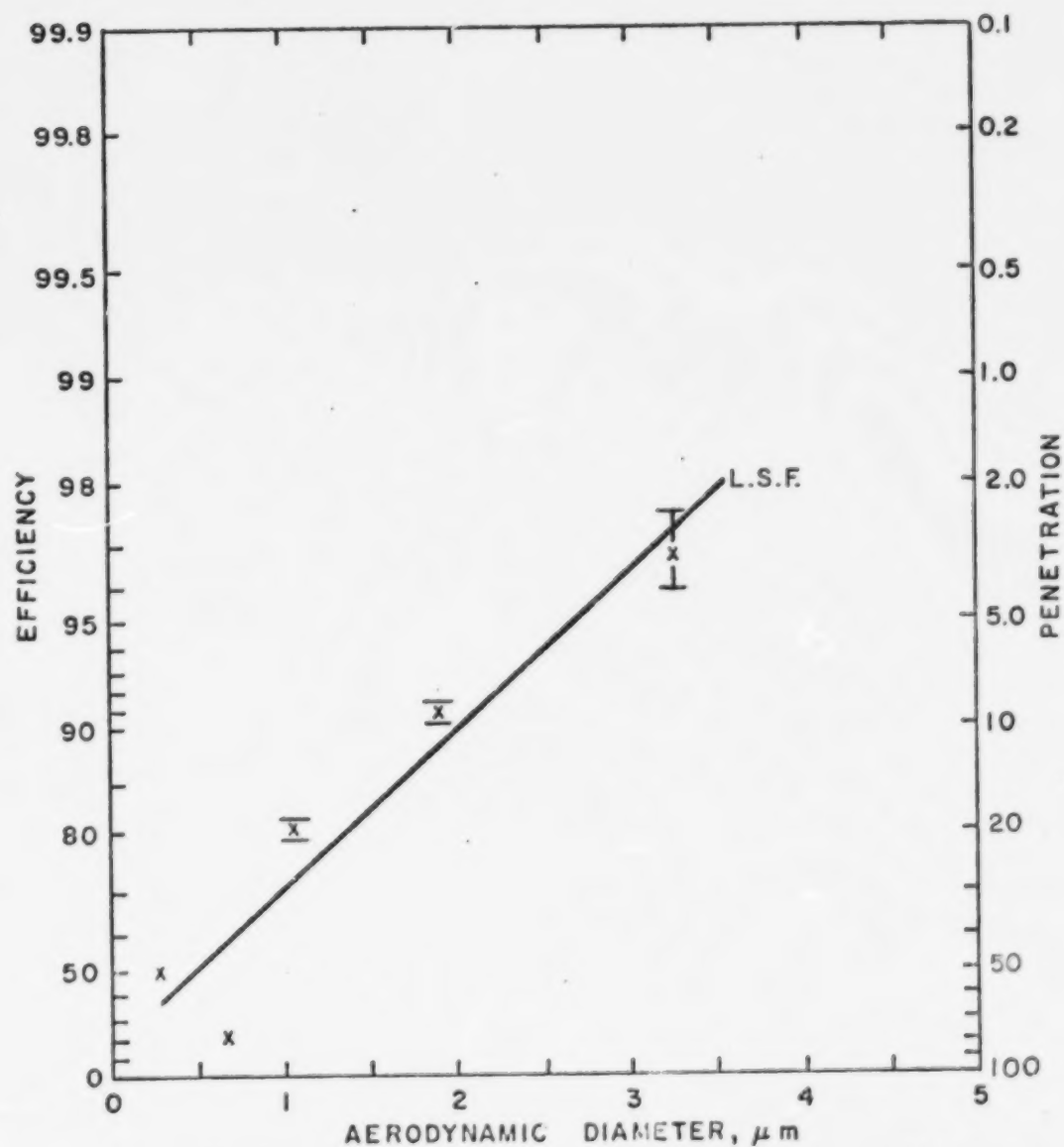


Figure 18. Dynactor collection efficiency versus aerodynamic diameter, averages of data for iron oxide at $0.47 \text{ m}^3/\text{s}$ (1000 cfm)

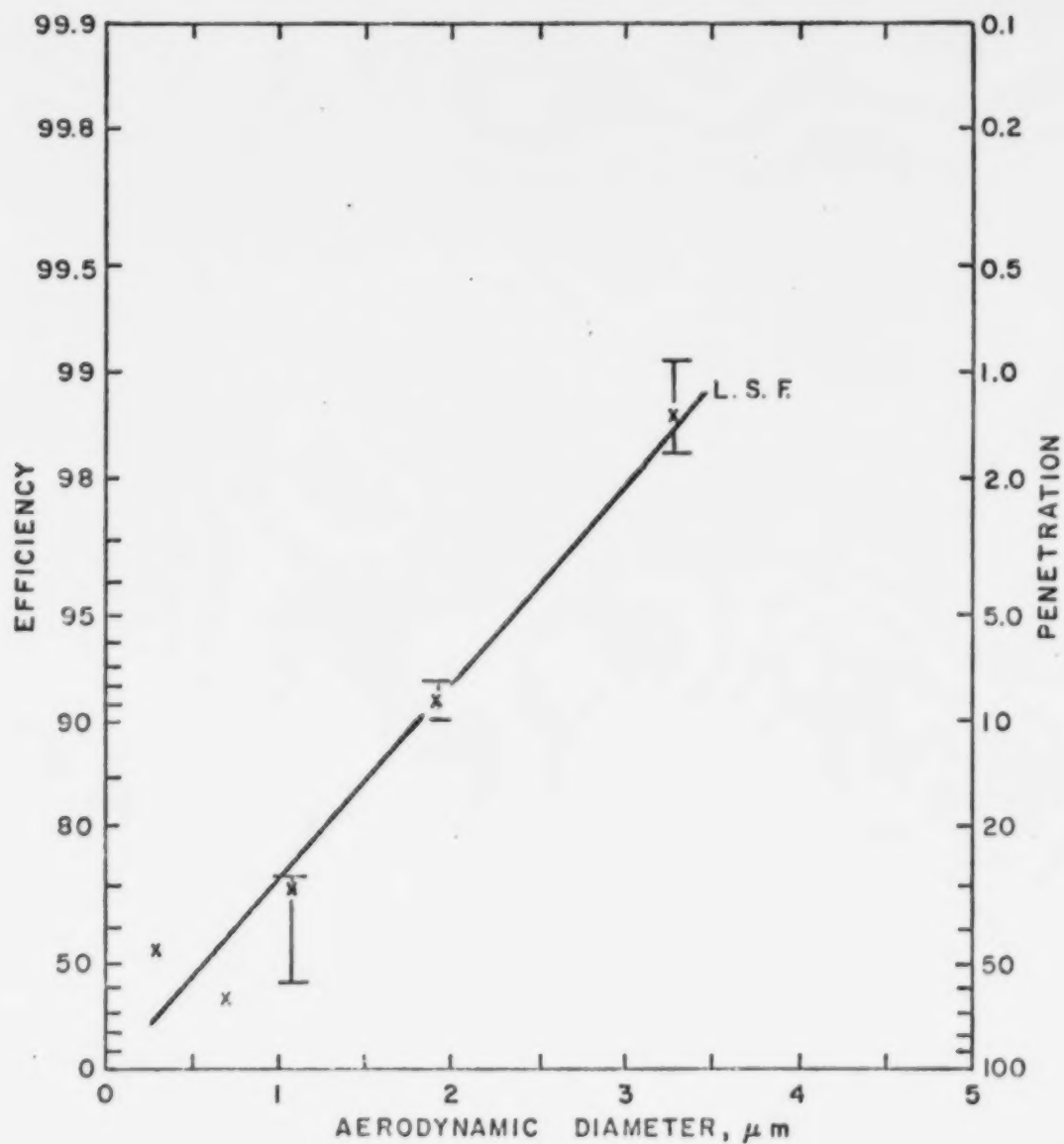


Figure 19. Dynactor collection efficiency versus aerodynamic diameter, averages of data for fly ash at $0.47 \text{ m}^3/\text{s}$ (1000 cfm)

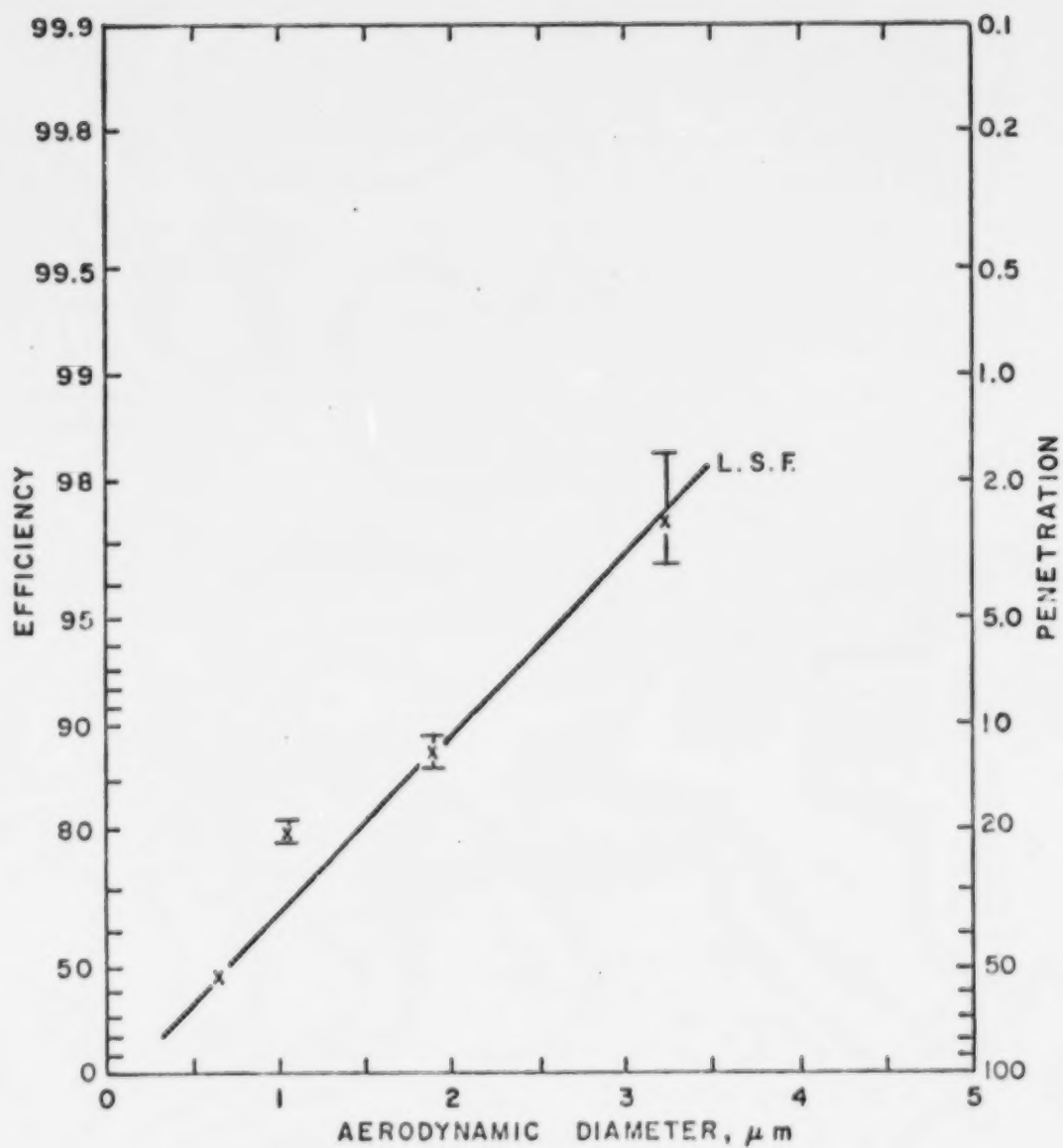


Figure 20. Dynactor collection efficiency versus aerodynamic diameter, averages of data for iron oxide at $0.71 \text{ m}^3/\text{s}$ (1500 cfm)

the frequent occurrence of infinite efficiencies resulting from the combination of a 0.0 mg/m^3 inlet concentration and a nonzero outlet concentration.)

In Table 14 have been listed the averages of the best and worst case analyses along with the averages of the efficiencies calculated from the original data for the three size fractions in which this best/worse case average approach was used. The differences between the raw data and the average of the best and worst case averages are generally negligible.

In Figures 16 to 20 the x's are the points from which the least squares fit was made, the average raw data values for stages 5, 6, 7 and the values used in the statistical tests for the smallest two size intervals. The bands shown are the averages of the best and the worst cases. (This data treatment emerged from a discussion with Control Systems Laboratory personnel.)

From the least squares fit line (L.S.F.) can be determined the aerodynamic cut diameter for the iron oxide and fly ash tests at the flow rates $0.23 \text{ m}^3/\text{s}$ (500 cfm), $0.47 \text{ m}^3/\text{s}$ (1000 cfm) and for the iron oxide at $0.71 \text{ m}^3/\text{s}$ (1500 cfm). The spray volume flow rate and the pressure at the nozzles was constant for these three air flow rates, so the power was constant. The three air flow rates meant three values of power per air volume flow rate.

Figure 21 is adapted from one presented by Calvert.³ It has aerodynamic cut diameter graphed against power per unit flow rate (hp/acfm). Also shown is the equivalent air pressure drop if all the power went to moving the volume of air through a flow resistance. The five average particle aerodynamic cut diameters have been drawn on this figure to allow comparisons with other scrubbers.

The Dynactor scrubber data points are scattered about the lower of the two lines (2b) in Figure 21, indicating that its power consumption is not

Table 14. BEST CASE AND WORST CASE AVERAGE EFFICIENCIES FOR DYNACTOR SCRUBBER
TESTS FOR FLY ASH AND IRON OXIDE AT THREE FLOW RATES

Test numbers	Flow rate	Aerosol	Impactor stage	Best case average	Worst case average	Average best/worst	Raw data average
4, 5, 23, 24	0.23 m ³ /s (500 cfm)	Iron oxide	5	98.1	97.4	97.8	97.9
			6	93.8	93.2	93.5	93.6
			7	84.6	82.5	83.6	83.3
7, 8, 26, 27	0.23 m ³ /s (500 cfm)	Fly ash	5	99.8	99.3	99.6	99.6
			6	96.5	95.5	96.0	96.0
			7	87.5	80.5	84.0	83.4
12, 14, (16, 17, 18), 19	0.47 m ³ /s (1000 cfm)	Iron oxide	5	97.6	96.0	96.8	97.1
			6	91.7	90.5	91.1	91.2
			7	81.9	79.1	80.5	80.3
4, 10, 21, 22	0.47 m ³ /s (1000 cfm)	Fly ash	5	99.1	98.3	98.7	98.9
			6	92.3	90.1	91.2	91.2
			7	71.4	41.2	56.3	68.6
29, 30	0.71 m ³ /s (1500 cfm)	Iron oxide	5	98.4	96.6	97.5	97.8
			6	89.4	86.8	88.1	88.2
			7	81.4	76.9	79.1	79.0

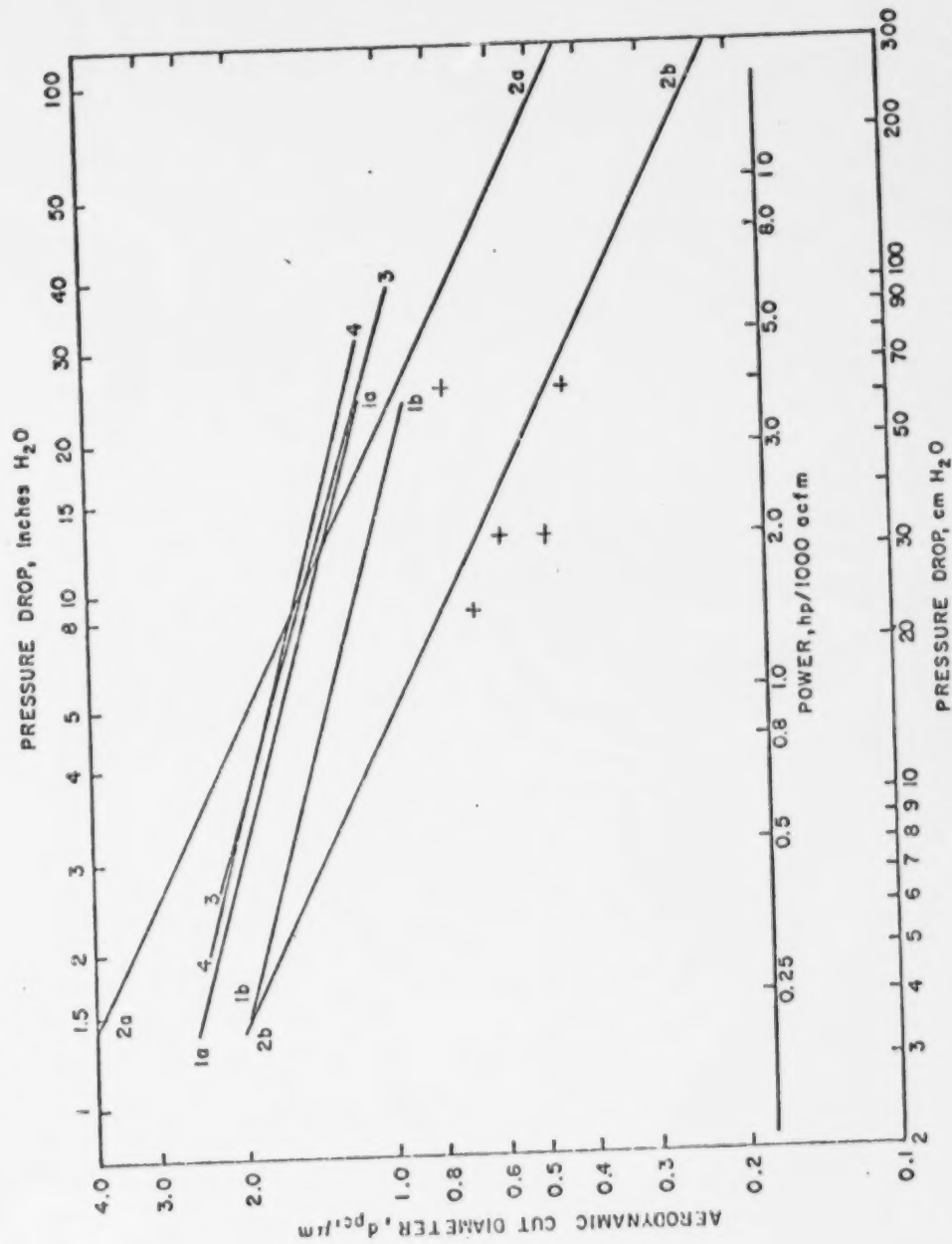


Figure 21. Aerodynamic cut diameter versus pressure drop across scrubber or power per unit volume flow, adapted from Calvert (1974). Lines 2a and 2b are for venturi scrubbers. Dynactor scrubber data averages are denoted by +'

substantially different from that of a well-designed venturi scrubber having the same particle collection efficiency as the Dynactor.

EFFECTS OF FLOW, DUST, TEMPERATURE, CONCENTRATION, ETC.

As noted in the results, there were statistically significant effects on collection efficiency due to flow, dust, temperature, and concentration of particulates. Here we will discuss these effects and link these results with those of others.

Flow

Increasing the flow rate will increase the velocity gradients, which would be expected to increase deposition due to impaction and interception and to increase the turbulent eddy diffusivity, which is a linear function of the Reynolds number (Calvert et al.),⁶ and thus increase the rate of mass transfer to the droplets. Increasing the flow rate will also decrease the residence time, which would give less time for the collection mechanisms to act, significant for the smallest particles, where diffusion would predominate the collection mechanisms, and for the largest particles, for which settling would become important. We found somewhat higher collection efficiencies at the lower flow rate, as did Lancaster and Strauss in their experiments with spray scrubbers, using ZnO particles with a number median diameter of 1.0 μm .

Dust

Particles of fly ash were consistently collected with greater efficiency than particles of iron oxide having the same aerodynamic diameter in our tests. Different aerodynamic behavior by particles having the same aerodynamic diameter is unexpected, but perhaps the particles differed in the likelihood with which a particle/droplet collision produced

capture or in the degree to which they served as nuclei during condensation or the degree to which high humidities facilitated their agglomeration. The iron oxide powder seemed less hydrophilic than did the fly ash, because water droplets beaded up on iron oxide layer and absorbed into a fly ash layer, thus the iron oxide may have been less wettable and more difficult for the water droplets to entrap. Lohs¹⁰ found that making hydrophobic polystyrene particles into hydrophilic ones, by coating their surfaces with a wetting agent, increased the capture of these particles by a spray scrubber. From their experiments with venturi scrubbers, Calvert, Lundgren, and Mehta⁶ concluded that particle wettability enhanced collection efficiency.

Temperature

Temperature can influence collection efficiency in a variety of ways. Higher temperatures means higher viscosity for gases; for example, as air goes from 20°C to 100°C, its viscosity increases a factor of 1.20 (Bird et al.),² which increases its resistance to particle motion, hindering the various collection mechanisms. For the sub-micron particles, this can be offset by the increase in the Cunningham slip correction factor as temperature increases and by the increase in the particle diffusivity due to Brownian motion. Our experiments showed a statistically significant decrease in collection efficiency for 1.3-2.5 μm aerodynamic diameter particles as temperature increased from 20°C to 95°C, as well as a general trend toward decreased efficiencies for all the aerosol size fractions. Lancaster and Strauss⁸ measured a decrease in efficiency in going from 20°C to 30°C with a spray scrubber operating on water-saturated air containing particulate material.

Concentration

As particle concentration increases, particle agglomeration increases due to coagulation. Increased agglomeration means an aerosol having

larger mean size, which generally enhances collection efficiency in spray scrubbers. Increased concentrations yielded higher collection efficiencies in all the aerosol size fractions in our tests. Lancaster and Strauss,⁸ among others, reported increased efficiency with increased mass loading. In our tests with the Dynactor, the improvement in collection was most dramatic for the smallest particles, indicative of coagulation.

Surfactant Addition

The addition of wetting agent, surfactant, to the spray water lowers the surface tension of the water, which would mean it improves the ability of the droplets to wet and engulf particles and it tends to decrease the droplet size of the spray, the latter being determined by the equilibrium between the force of surface tension and the forces tending to break up the droplets. Improved wetting should improve collection efficiency in situations where poor wetting is an inhibitor, which we believe was the situation with iron oxide. Smaller droplet sizes generally improve collection efficiency as well, for a given droplet mass concentration. Our results showed a trend toward a slight improvement in efficiencies using a surfactant additive.

Water Vapor Addition, Diffusiophoresis, Thermophoresis

Lapple and Kamack⁹ were among the first of many to note that the addition of steam upstream from a scrubber could produce substantial improvements in collection efficiencies. Lohs¹⁰ attributed the enhancement of efficiency, which he too measured, to the following causes: condensation on the particles which made them into relatively massive droplets, improved adhesion between particles and particles and between particles and spray droplets, diffusiophoresis. Sparks and Pilat¹² calculated the contribution of diffusiophoresis to collection by spray droplets and concluded the effect could be dramatic,

increasing for smaller particles and lower gas/droplet relative velocities. On the other hand, Slinn and Hales¹¹ analyzed the roles played by thermophoresis and diffusiophoresis in the scavenging of atmospheric aerosols by cloud droplets and concluded that thermophoresis generally predominates.

If the condensation process begins with a drop which is at the ambient temperature, then the condensation heats the drop and this heating produces an opposing thermophoresis; if evaporation begins with the drop at ambient temperature, these two mechanisms are reversed and still oppose each other. Relatively hot droplets which evaporate will repel particles due to both diffusiophoresis and thermophoresis until they cool to below ambient temperatures; relatively cool droplets which condense moisture will attract particles by both mechanisms until they heat to above ambient temperatures. For droplets starting at the ambient temperature (T_{∞}), condensation causes the droplet to heat up due to the latent heat of condensation, λ , and thermal forces inhibit collection. An approximate ratio of the two flux forces was given by Slinn and Hales¹¹ as:

$$\frac{\text{thermophoresis}}{\text{diffusiophoresis}} = - \frac{M_a \lambda}{5 R T_{\infty}}$$

where

M_a = "molecular weight" of air,

λ = latent heat of evaporation/condensation

R = gas constant

T_{∞} = temperature of the fluid medium

from which they computed that thermophoretic transport will exceed diffusiophoretic transport by a factor of about 6 and oppose it. Lancaster and Strauss⁸ tried to separate the effects of these flux force mechanisms from the effects of particle size increase and

adhesion improvement due to water vapor. They used cold and hot sprays to scrub water-saturated air and found no improvement with the cold spray, which would have produced greater condensation upon the spray droplets and would have produced an enhancing thermophoresis. Lancaster and Strauss did find that steam addition helped increase collection efficiency, decreasing the particle penetration by a factor of $(1 - 5Q)$, Q being the mass ratio of steam to air; this increase they attributed to particle build-up due to condensation. A recent survey of "flux force/condensation scrubbing," the use of steam with spray scrubbers, concluded that particle growth probably predominates over diffusiophoresis as the enhancement mechanism (Calvert et al.)⁴ for multistage devices. The relative roles of these mechanisms seem as yet in question, but they are important considerations in the design of scrubbers: if the improvement in collection efficiency is due to particle build-up, then steam should be added as early in the flow as practicable; if diffusiophoresis is enhancing collection and doing so more vigorously than particle build-up, then the steam should be added just shortly before the scrubbing takes place.

Recent experimental work by Semrau and Witham¹⁴ of Stanford Research Institute demonstrated enhanced collection due to condensation for steam to air ratios near 0.3. It was concluded that such collection by condensation would not be a practical alternative to conventional high energy scrubbing but can supplement it, especially where waste heat or high water vapor contents are already available.

Although we did not find a major improvement in efficiency when we used ~ 0.05 water vapor to air ratio, this ratio was about one-third that ratio recommended in the study of "flux force scrubbing" by Calvert et al., (1973).⁴

SECTION VII

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SECTION IX

APPENDIXES

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APPENDIX A

MANUFACTURER'S DESCRIPTION OF DYNACTOR

The continuous gas/liquid contactor, the Dynactor, is a proprietary development of R P Industries, Inc. Figure A-1 is a cross section of a single stage Dynactor diffusion contactor. Liquid entering the system under a pressure of 140 to 200 pounds per square inch (typical) is atomized into thin films and droplets of average thickness or diameter less than 1/64 inch. This liquid discharge diffuses or expands into the reaction chamber causing air or gas to be aspirated by being trapped within the moving shower of films and particles. The resulting mixed fluid then continues to travel down the reaction column with intimate contact maintained between gas and liquid. This causes physical and chemical equilibria to occur by the time the mixed fluid exits from the reaction column into the separation reservoir. The Dynactor can be viewed as a macroscopic diffusion pump which makes use of diffusion principles in order to aspirate large volumes of air per volume of motive liquid. By utilizing diffusion rather than Bernoulli principles, the Dynactor aspirates up to 4,800 standard volumes of gas per volume of motive liquid. In comparison, venturi eductors will aspirate not more than 100 volumes of gas per volume of motive liquid.

Because there are no venturi or other constrictions in the Dynactor, energy requirements are considerably lower than for conventional jet or venturi eductor systems. If gas carries small solid particles along with it, such as activated carbon or powdered neutralizing and precipitating agents, such particles are wetted and captured by the

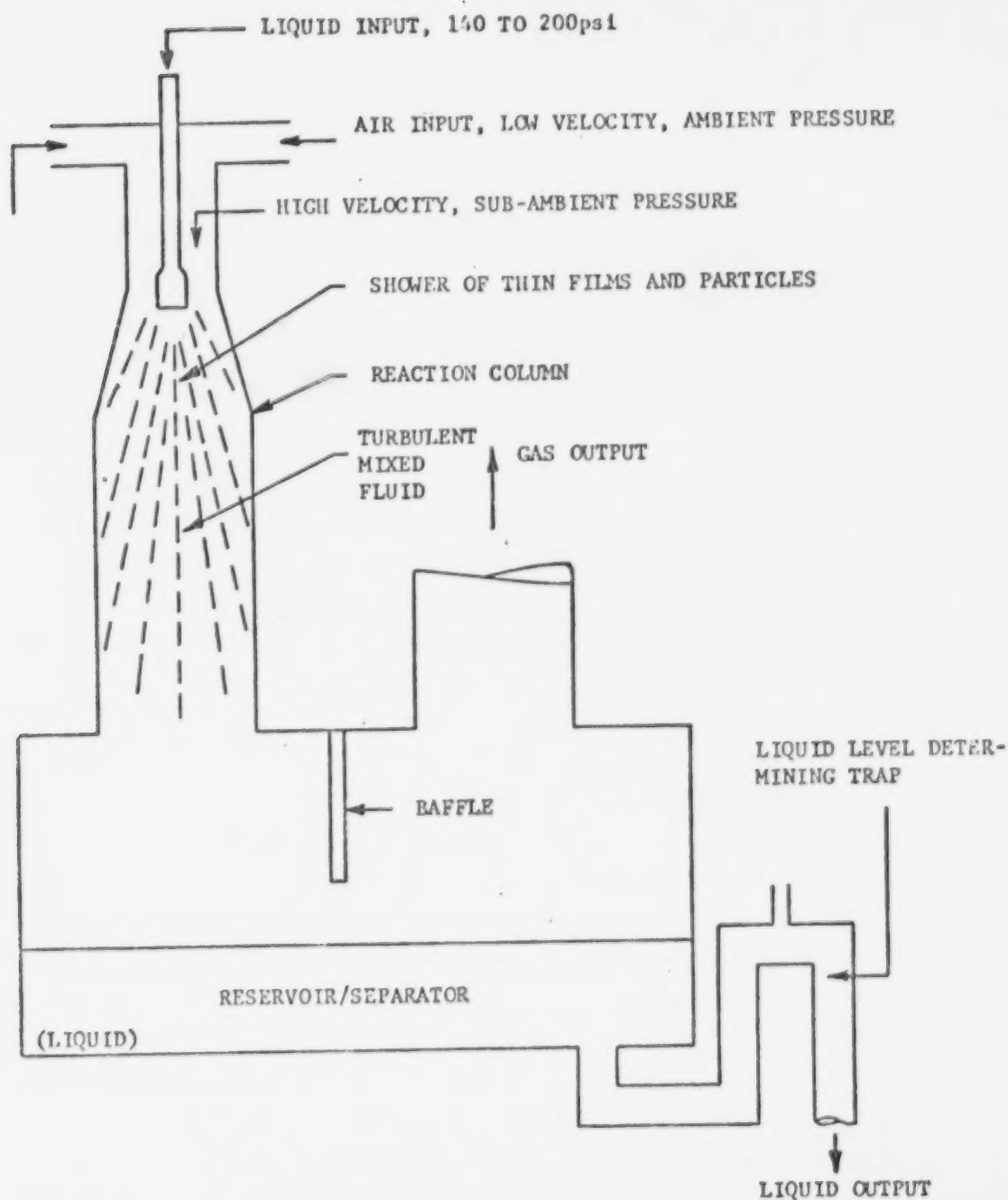


Figure A-1. Single-stage Dynactor diffusion system cross sectional view

liquid throughout the entire length of the reaction chamber. By contrast, venturi wet scrubbers make effective contact between gas and liquid only in the constricted throat region. Contact time, therefore, in the Dynactor is about 20 times longer than in venturi devices.

Just as in oil and mercury diffusion vacuum pumps, it is also possible to construct Dynactors having multistage gas inputs. Figure A-2 is a drawing of the two-stage Dynactor diffuser system employed in these studies. The internal configuration was constructed to maximize gas/liquid turbulence and contact throughout the length of the six-foot long, 12-inch diameter reaction column.

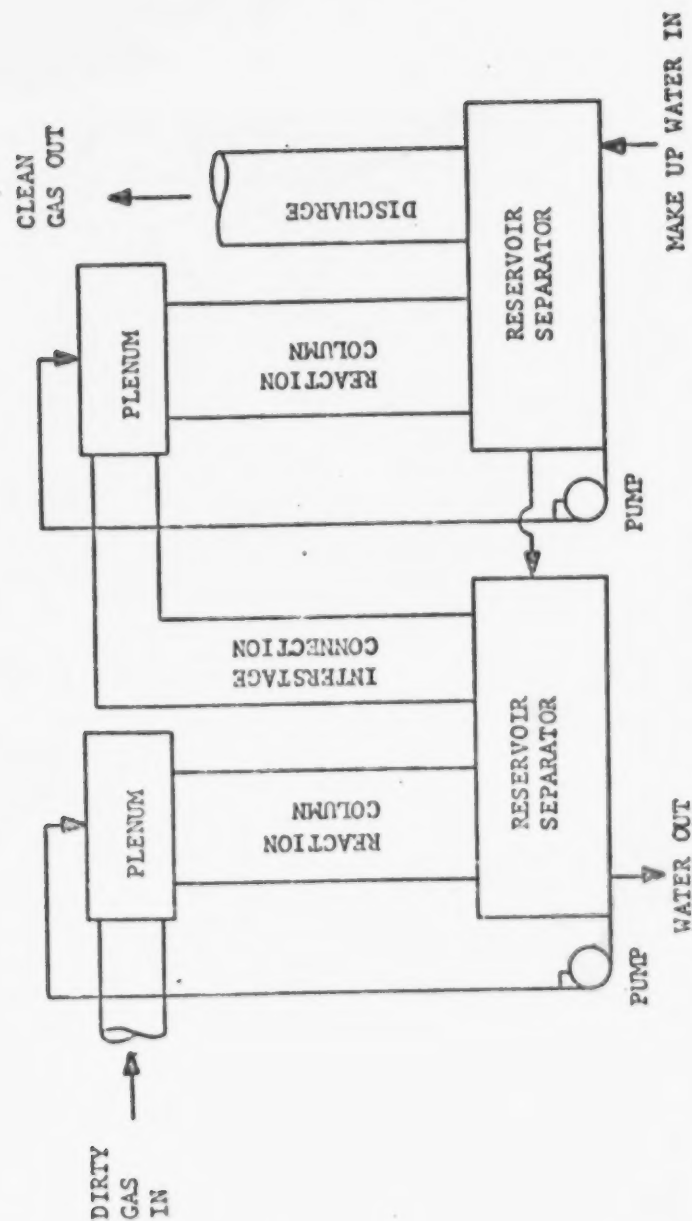


Figure A-2. Two-stage Dynactor

APPENDIX B

DYNACTOR EFFICIENCY DATA

This appendix presents all the data on the Dynactor efficiency tests used as a basis for the Dynactor evaluation. It includes the tests for the balanced 2^4 factorial design study, as well as tests involving flow at 1500 cfm ($0.71 \text{ m}^3/\text{s}$), moisture addition with a spray nozzle upstream from the Dynactor, use of surfactant in the Dynactor spray, and testing of a single stage of the two-stage device.

The efficiency data sheets, one for each individual set of test conditions, contain the following information:

- Test identification number
- Concentration at Dynactor inlet
- Concentration at Dynactor outlet
- Total mass efficiency, based on the preceding two numbers
- Aerosol material used in test
- Air flow through Dynactor
- Volume rate of flow of Dynactor spray
- Temperature at Dynactor inlet
- Remarks, where appropriate
- Flow rate and sample duration for the various sampling devices
- Fractional efficiency data, including:
 - Limits, aerodynamic diameter, of size interval
 - Concentration of aerosol in that size interval at Dynactor inlet
 - Concentration of aerosol in that size interval at Dynactor outlet

- Mass efficiency on particles of sizes in that size interval, based on the preceding two numbers
- Total concentrations measured by the Andersen impactors at inlet and outlet and mass efficiency based on them

As discussed in the report, the substrate material onto which impaction occurred sometimes showed a weight loss or a weight gain that was less than 0.3 mg. These small or negative weight changes were given the same value, ≤ 0.3 mg, which was used to derive those efficiencies given as inequalities. The concentrations derived from these inequalities and the efficiencies calculated therefrom are marked with an asterisk to emphasize that they are assumed values.

The following tests were run but not reported for the reasons indicated:

- #1 - Sample nozzles not blocked when not sampling.
- #2 - Sample nozzles not blocked when not sampling.
- #3 - Dynactor components melted at 300°F.
- #6 - Downstream sampling time too short for appreciable impactor weights.
- #11 - Inlet dust concentration too low (0.03 gr/ft³)
- #15 - Downstream impactor not connected to pump.
- #20 - Screw feed auger failed.

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 4
 AEROSOL Iron oxide
 NOZZLE: 200 psig = 1.4×10^4 cm WC
 FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min = 1.16×10^{-3} m³/sec
 TEMPERATURE: 70 °F = 21 °C

INLET CONCENTRATION .86 gr/ft³ = 1979 mg/m³
 OUTLET CONCENTRATION .031 gr/ft³ = 71.4 mg/m³
 TOTAL MASS EFFICIENCY .964

REMARKS: Size distribution obtained from impactors at 1.0 cfm flow was interpolated to match sizing intervals for impactors at 0.5 cfm flow.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	1.	1.0	= .028
INLET IMPACTOR	1.0	= .028	1.	1.0	= .028
OUTLET TOTAL FILTER	1.0	= .028	15.	15.0	= .43
OUTLET IMPACTOR	1.0	= .028	15.	15.0	= .43

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	> 9.0	< 10.6*	≤ .7*	--
2	6.0 - 9.0	< 31.8*	≤ .7*	--
3	4.0 - 6.0	106.0	1.2	--
4	2.8 - 4.0	191.0	2.8	98.5
5	1.8 - 2.8	311.0	8.5	97.3
6	0.90 - 1.8	374.0	29.9	92.0
7	.54 - 0.90	31.8	17.7	44.4
8	0.36 - 0.54	≤ 10.6*	3.1	≤ 71.1*
Final filter	0.36	17.7	1.4	92.0
TOTAL, Andersen Impactor		1074.	66.0	93.9

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 5 INLET CONCENTRATION ~ .8 gr/ft³ = ~2000 mg/m³
 AEROSOL Iron oxide OUTLET CONCENTRATION .040 gr/ft³ = 91.4 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY ~ .95
 FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 205 °F = 97 °C

REMARKS: Size distribution obtained by impactors at 1.0 cfm flow was interpolated to match sizing intervals for impactors at 0.5 cfm flow.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	1.	1.0	= .028
INLET IMPACTOR	1.0	= .028	1.	1.0	= .028
OUTLET TOTAL FILTER	1.0	= .028	15.	15.	= .43
OUTLET IMPACTOR	1.0	= .028	15.	15.	= .43

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	> 9.0	≤ 3.5*	--	--
2	6.0 - 9.0	21.2	--	--
3	4.0 - 6.0	88.3	--	--
4	2.8 - 4.0	166.0	1.4	--
5	1.7 - 2.8	265.0	6.8	97.4
6	0.90 - 1.8	322.0	13.0	96.0
7	0.54 - 0.90	28.3	23.6	16.7
8	0.36 - 0.54	≤ 10.6*	4.2	≤ 60.0*
Final filter	0.36	≤ 10.6*	.7	≤ 93.3*
TOTAL, Andersen Impactor		898.0	49.7	94.3

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 7

AEROSOL Fly ash

NOZZLE: 200 psig = 1.4 x 10⁴ cm WC

FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec

TEMPERATURE: 200 °F = 95 °C

INLET CONCENTRATION ~ 0.7 gr/ft³ = ~1600 mg/m³

OUTLET CONCENTRATION .0059 gr/ft³ = 13.6 mg/m³

TOTAL MASS EFFICIENCY ~ .99

REMARKS: Inlet concentration sampler malfunctioned, so inlet concentration (0.7 gr/ft³) estimated from other tests.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	3.	3.0	= .085
INLET IMPACTOR	.5	= .014	3.	1.5	= .043
OUTLET TOTAL FILTER	1.0	= .028	69.	69.	= 1.95
OUTLET IMPACTOR	.5	= .014	90.	45.	= 1.27

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m^3)	OUTLET CONCENTRATION (mg/m^3)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	37.7	$\leq .24^*$	--
2	8.6 - 13.6	118.	$\leq .24^*$	--
3	5.6 - 8.6	186.	$\leq .24^*$	--
4	4.0 - 5.6	141.	$\leq .24^*$	--
5	2.5 - 4.0	113.	.5	99.5
6	1.3 - 2.5	82.	3.2	96.1
7	0.80 - 1.3	21.2	4.0	81.1
8	0.54 - 0.80	$\leq 7.1^*$	2.9	$\leq 58.9^*$
Final filter	≤ 0.54	$\leq 7.1^*$	4.0	$\leq 43.3^*$
TOTAL, Andersen Impactor		704.	14.9	97.9

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 8
 AEROSOL Fly ash
 NOZZLE: 200 psig = 1.4×10^4 cm WC
 FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min = 1.16×10^{-3} m³/sec
 TEMPERATURE: 70 °F = 21 °C

INLET CONCENTRATION .90 gr/ft³ = 2076 mg/m³
 OUTLET CONCENTRATION .0067 gr/ft³ = 15.4 mg/m³
 TOTAL MASS EFFICIENCY .993

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	2.	2.0	= .057
INLET IMPACTOR	.5	= .014	3.	1.5	= .043
OUTLET TOTAL FILTER	1.0	= .028	88.	88.	= 2.49
OUTLET IMPACTOR	.5	= .014	90.	45.	= 1.37

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	61.2	≤ .2*	--
2	8.6 - 13.6	160.	≤ .2*	--
3	5.6 - 8.6	278.	≤ .2*	--
4	4.0 - 5.6	151.	≤ .2*	--
5	2.5 - 4.0	132.	.5	99.6
6	1.3 - 2.5	80.	3.5	95.6
7	0.80 - 1.3	19.	4.1	78.3
8	0.54 - 0.80	≤ 7.0*	3.0	≤ 57.8*
Final filter	≤ 0.54	≤ 7.0*	2.0	≤ 72.2*
TOTAL, Andersen Impactor		881.	13.4	98.5

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST #9
 AEROSOL Fly Ash
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC
 FLOW: 1000 ft³/min = 28.3 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 68 °F = 20 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	10.	20.	= .57
INLET IMPACTOR	0.5	= .014	26.	13.	= .37
OUTLET TOTAL FILTER	2.0	= .057	296.	592.	= 16.8
OUTLET IMPACTOR	0.5	= .014	300.	150.	= 4.3

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	7.3	≤ .07 *	--
2	8.6 - 13.6	16.3	≤ .07 *	--
3	5.6 - 8.6	29.6	≤ .07 *	--
4	4.0 - 5.6	22.3	≤ .07 *	--
5	2.5 - 4.0	20.9	.14	99.3
6	1.3 - 2.5	13.0	.82	93.7
7	0.80 - 1.3	4.9	1.2	74.5
8	0.54 - 0.80	≤ .8*	.72	≤ 50.9*
Final filter	≤ 0.54	≤ .8*	.40	≤ 10.4*
TOTAL, Andersen Impactor		114.	3.3	97.0

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 10 INLET CONCENTRATION $0.17 \text{ gr/ft}^3 = 396 \text{ mg/m}^3$
AEROSOL Fly ash OUTLET CONCENTRATION $.0015 \text{ gr/ft}^3 = 3.5 \text{ mg/m}^3$
NOZZLE: 200 psig = $1.4 \times 10^4 \text{ cm WC}$ TOTAL MASS EFFICIENCY .991
FLOW: $1000 \text{ ft}^3/\text{min} = 28.3 \text{ m}^3/\text{min}$ Total Spray: $18.4 \text{ gal/min} = 1.16 \times 10^{-3} \text{ m}^3/\text{sec}$
TEMPERATURE: $200^\circ\text{F} = 95^\circ\text{C}$

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	10	20	= .57
INLET IMPACTOR	0.5	= .014	20	10	= .28
OUTLET TOTAL FILTER	2.0	= .057	240	480	= 13.6
OUTLET IMPACTOR	0.5	= .014	240	120	= 3.4

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	3.2	$\leq .09^*$	--
2	8.6 - 13.6	12.7	$\leq .09^*$	--
3	5.6 - 8.6	25.1	$\leq .09^*$	--
4	4.0 - 5.6	15.5	$\leq .09^*$	--
5	2.5 - 4.0	14.1	.15	99.0
6	1.3/ - 2.5	9.9	.8	92.0
7	0.80 - 1.3	1.4	1.2	12.5
8	0.54 - 0.80	$\leq 1.1^*$	.7	$\leq 36.1^*$
Final filter ≤ 0.54		$\leq 1.1^*$	.6	$\leq 44.4^*$
TOTAL, Andersen Impactor		82.3	3.45	95.8

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 12 INLET CONCENTRATION .244 gr/ft³ = 560 mg/m³
 AEROSOL Iron oxide OUTLET CONCENTRATION .0244 gr/ft³ = 56 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY .900
 FLOW: 1000 ft³/min = 28.3 m³/min Total Spray: 18.4 gal/min₃ = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 70 °F = 21 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	5	10	= .28
INLET IMPACTOR	0.5	= .014	10	5	= .14
OUTLET TOTAL FILTER	2.0	= .057	50	100	= 2.8
OUTLET IMPACTOR	0.5	= .014	120	60	= 1.7

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	≤ 2.1*	≤ .2*	--
2	8.6 - 13.6	16.3	≤ .2*	--
3	5.6 - 8.6	34.6	.4	99.0
4	4.0 - 5.6	67.1	1.0	98.5
5	2.5 - 4.0	124.	3.8	96.9
6	1.3 - 2.5	188.	14.6	92.3
7	0.80 - 1.3	146.	21.4	85.3
8	0.54 - 0.80	25.4	18.2	28.5
Final filter	≤ 0.54	≤ 2.1*	6.4	≤ 0.0*
TOTAL, Andersen Impactor		605.	65.9	89.1

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 13	INLET CONCENTRATION	.33 gr/ft ³ = 747 mg/m ³
AEROSOL: Iron oxide	OUTLET CONCENTRATION	.059 gr/ft ³ = 135 mg/m ³
NOZZLE: 100 psig = 7 x 10 ³ cm H ₂ O	TOTAL MASS EFFICIENCY	.818
FLOW: 1000 ft ³ /min = 28.3 m ³ /min	Total Spray:	13.2 gal/min
TEMPERATURE: 80 °F = 27 °C		= .58 x 10 ⁻³ m ³ /sec
REMARKS: Nozzles used at 100 p.s.i.g. = 6.9 x 10 ⁵ N/M ²		

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	4.0	8.0	= .23
INLET IMPACTOR	.5	= .014	4.0	2.0	= .057
OUTLET TOTAL FILTER	2.0	= .057	40.	80.	= 2.3
OUTLET IMPACTOR	.5	= .014	40.	20.	= .57

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m^3) .	OUTLET CONCENTRATION (mg/m^3)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	$\leq 5.3^*$	1.6	--
2	8.6 - 13.6	7.1	1.6	77.5
3	5.6 - 8.6	33.6	2.3	93.2
4	4.0 - 5.6	54.8	5.3	90.3
5	2.5 - 4.0	124.	15.4	87.6
6	1.3 - 2.5	210.	45.4	78.4
7	0.80 - 1.3	147.	59.	60.0
8	0.54 - 0.80	15.9	15.9	0.0
Final filter	≤ 0.54	$\leq 5.3^*$	5.5	$\leq 0.0^*$
TOTAL, Andersen Impactor		599.	152.	74.6

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 14	INLET CONCENTRATION .118 gr/ft ³ = 271 mg/m ³
AEROSOL: Iron oxide	OUTLET CONCENTRATION .016 gr/ft ³ = 36.6 mg/m ³
NOZZLE: 200 psig = 1.4 x 10 ⁴ cm WC	TOTAL MASS EFFICIENCY .866
FLOW: 1000 ft ³ /min = 28.3 m ³ /min	Total Spray: 18.4 gal/min = 1.16 x 10 ³ m ³ /sec
TEMPERATURE: 203 °F = 95 °C	

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	4.	8.	= .226
INLET IMPACTOR	0.5	= .014	4.	2.	= .057
OUTLET TOTAL FILTER	2.0	= .057	40.	80.	= 2.26
OUTLET IMPACTOR	0.5	= .014	40.	20.	= .566

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	< 5.2*	< .5*	--
2	8.6 - 13.6	< 5.2*	< .5*	--
3	5.6 - 8.6	7.1	< .5*	--
4	4.0 - 5.6	10.6	< .5*	--
5	2.5 - 4.0	30.0	1.4	95.3
6	1.3 - 2.5	97.2	10.4	89.3
7	0.80 - 1.3	67.1	15.9	76.3
8	0.54 - 0.80	< 5.2*	8.1	≤ 0*
Final filter	≤ 0.54	< 5.2*	< .5*	-
TOTAL, Andersen Impactor		215.5	36.0	83.3

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 16 INLET CONCENTRATION 1.01 gr/ft³ = 2311 mg/m³
AEROSOL Iron oxide OUTLET CONCENTRATION .047 gr/ft³ = 107 mg/m³
NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY .954
FLOW: 1000 ft³/min = 28.3 m³/min Total Spray: 18.4 gal/min₃ = 1.16 x 10³ m³/sec
TEMPERATURE: 63 °F = 17 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	1.0	2.0	= .057
INLET IMPACTOR	0.5	= .014	2.0	1.0	= .028
OUTLET TOTAL FILTER	2.0	= .057	4.5	9.0	= .255
OUTLET IMPACTOR	0.5	= .014	15.0	7.5	= .212

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL LII

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	49.5	≤ 1.4*	--
2	8.6 - 13.6	70.7	≤ 1.4*	--
3	5.6 - 8.6	159.	≤ 1.4*	--
4	4.0 - 5.6	180.	≤ 1.4*	--
5	2.5 - 4.0	254.	4.7	98.1
6	1.3 - 2.5	375.	25.4	93.2
7	0.80 - 1.3	258.	33.0	87.2
8	0.54 - 0.80	60.1	17.4	71.0
Final filter	≤ 0.54	17.7	≤ 1.4*	≥ 92.0*
TOTAL, Andersen Impactor		1424.	81.5	94.3

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 17	INLET CONCENTRATION	.84 gr/ft ³ = 1922 mg/m ³
AEROSOL Iron oxide	OUTLET CONCENTRATION	.042 gr/ft ³ = 96 mg/m ³
NOZZLE: 200 psig = 1.4 x 10 ⁴ cm WC	TOTAL MASS EFFICIENCY	.950
FLOW: 1000 ft ³ /min = 28.3 m ³ /min	Total Spray:	18.4 gal/min = 1.16 x 10 ³ m ³ /sec
TEMPERATURE: 70 °F = 21 °C		

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	1.	2.0	= .057
INLET IMPACTOR	0.5	= .014	2.	1.0	= .028
OUTLET TOTAL FILTER	2.0	= .057	15.	30.	= .85
OUTLET IMPACTOR	0.5	= .014	15.	7.5	= .21

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	24.7	≤ 1.4*	--
2	8.6 - 13.6	53.0	≤ 1.4*	--
3	5.6 - 8.6	148.	≤ 1.4*	--
4	4.0 - 5.6	187.	1.9	--
5	2.5 - 4.0	307.	5.2	98.3
6	1.3 - 2.5	382.	25.9	93.2
7	0.80 - 1.3	205.	39.1	80.9
8	0.54 - 0.80	21.2	18.4	13.3
Final filter	≤ 0.54	≤ 10.7*	2.8	≤ 73.3*
TOTAL, Andersen Impactor		1336.	95.2	92.9

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 18
 AEROSOL Iron oxide
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC
 FLOW: 1000 ft³/min = 28.3 m³/min
 TEMPERATURE: 70 °F = 21 °C

INLET CONCENTRATION .872 gr/ft³ = 1996 mg/m³
 OUTLET CONCENTRATION .038 gr/ft³ = 86.6 mg/m³
 TOTAL MASS EFFICIENCY .957
 Total Spray: 18.4 gal/min
 = 1.16 x 10⁻³ m³/sec

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	1.0	2.0	= .057
INLET IMPACTOR	0.5	= .014	2.0	1.0	= .028
OUTLET TOTAL FILTER	2.0	= .057	15.0	30.	= .85
OUTLET IMPACTOR	0.5	= .014	15.0	7.5	= .21

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	21.2	≤ 1.4*	--
2	8.6 - 13.6	53.0	≤ 1.4*	--
3	5.6 - 8.6	198.	≤ 1.4*	--
4	4.0 - 5.6	205.	≤ 1.4*	--
5	2.5 - 4.0	322.	2.8	99.1
6	1.3 - 2.5	343.	24.0	93.0
7	0.80 - 1.3	198.	33.5	83.1
8	0.54 - 0.80	28.3	12.7	55.0
Final filter ≤ 0.54		≤ 10.7*	1.9	≤ 82.2*
TOTAL, Andersen Impactor		1378.	74.9	94.6

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 19 INLET CONCENTRATION .679 gr/ft³ = 1553 mg/m³
 AEROSOL Iron oxide OUTLET CONCENTRATION .035 gr/ft³ = 79.1 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY .949
 FLOW: 1000 ft³/min = 28.3 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 203 °F = 95 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	1.0	2.0	= .057
INLET IMPACTOR	0.5	= .014	2.0	1.0	= .028
OUTLET TOTAL FILTER	2.0	= .057	14.0	28.	= .792
OUTLET IMPACTOR	0.5	= .014	14.0	7.	= .198

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	24.7	≤ 1.5*	--
2	8.6 - 13.6	56.5	≤ 1.5*	--
3	5.6 - 8.6	191.	≤ 1.5*	--
4	4.0 - 5.6	166.	≤ 1.5*	--
5	2.5 - 4.0	272.	6.6	97.6
6	1.3 - 2.5	286.	28.8	89.9
7	0.80 - 1.3	170.	40.9	75.9
8	0.54 - 0.80	17.7	15.6	11.4
Final filter	≤ 0.54	≤ 10.7*	3.5	≤ 66.7*
TOTAL, Andersen Impactor		1194.	98.9	91.7

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 21	INLET CONCENTRATION .955 gr/ft ³ = 2186 mg/m ³
AEROSOL Fly ash	OUTLET CONCENTRATION .011 gr/ft ³ = 25.3 mg/m ³
NOZZLE: 200 psig = 1.4 x 10 ⁴ cm WC	TOTAL MASS EFFICIENCY .988
FLOW: 1000 ft ³ /min = .283 m ³ /min	Total Spray: 18.4 gal/min = 1.16 x 10 ⁻³ m ³ /sec
TEMPERATURE: 70 °F = 21 °C	

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	3.0	6.0	= .171
INLET IMPACTOR	0.5	= .014	3.0	1.5	= .042
OUTLET TOTAL FILTER	2.0	= .057	57.5	115.	= 3.25
OUTLET IMPACTOR	0.5	= .014	60.0	30.	= .84

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	40.0	≤ .4 *	--
2	8.6 - 13.6	75.4	≤ .4 *	--
3	5.6 - 8.6	153.	≤ .4 *	--
4	4.0 - 5.6	115.	≤ .4 *	--
5	2.5 - 4.0	80.1	1.2	98.5
6	1.3 - 2.5	73.0	6.8	90.6
7	0.80 - 1.3	28.3	11.0	61.3
8	0.54 - 0.80	≤ 7.1 *	5.9	≤ 16.7 *
Final filter ≤ 0.54		≤ 7.1	1.1	≤ 85.0 *
TOTAL, Andersen Impactor		575.	26.4	99.4

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 22 INLET CONCENTRATION 1.30 gr/ft³ = 2984 mg/m³
 AEROSOL Fly ash OUTLET CONCENTRATION .012 gr/ft³ = 27.4 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY .991
 FLOW: 1000 ft³/min = 28.3 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 203 °F = 95 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	3.0	6.0	= .171
INLET IMPACTOR	0.5	= .014	3.0	1.5	= .042
OUTLET TOTAL FILTER	2.0	= .057	58.0	116.	= 3.28
OUTLET IMPACTOR	0.5	= .014	60.0	30.	= .84

FRACTIONAL EFFICIENCY DATA. ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	84.8	≤ .4*	--
2	8.6 - 13.6	155.	≤ .4*	--
3	5.6 - 8.6	229.	≤ .4*	--
4	4.0 - 5.6	127.	≤ .4*	--
5	2.5 - 4.0	115.	1.4	98.8
6	1.3 - 2.5	80.1	9.2	88.5
7	0.80 - 1.3	30.6	9.2	70.0
8	0.54 - 0.80	≤ 7.1*	4.6	≤ 35.0*
Final filter	≤ 0.54	≤ 7.1*	1.8	≤ 75.0*
TOTAL, Andersen Impactor		822.	26.9	96.7

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 23
 AEROSOL Iron oxide
 NOZZLE: 200 psig = 1.4×10^4 cm WC
 FLOW: 500 ft³/min = 14.2 m³/min
 TEMPERATURE: 66 °F = 19 °C

INLET CONCENTRATION .178 gr/ft³ = 408 mg/m³
 OUTLET CONCENTRATION .010 gr/ft³ = 23.2 mg/m³
 TOTAL MASS EFFICIENCY .943
 Total Spray: 18.4 gal/min = 1.16×10^{-3} m³/sec

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	15	15.0	= .424
INLET IMPACTOR	0.5	= .014	15	7.5	= .212
OUTLET TOTAL FILTER	1.0	= .028	118	118	= 3.34
OUTLET IMPACTOR	0.5	= .014	120	60	= 1.70

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL 111

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	≤ 1.4*	≤ .2*	--
2	8.6 - 13.6	≤ 1.4*	≤ .2*	--
3	5.6 - 8.6	6.1	≤ .2*	--
4	4.0 - 5.6	12.2	≤ .2*	--
5	2.5 - 4.0	27.3	.6	97.8
6	1.3 - 2.5	48.5	4.4	91.0
7	0.80 - 1.3	32.5	7.6	76.6
8	0.54 - 0.80	1.9	4.9	≤ 0 *
Final filter	≤ 0.54	≤ 1.4*	1.1	≤ 25.0*
TOTAL, Andersen Impactor		131.	18.7	85.6

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 24 INLET CONCENTRATION .187 gr/ft³ = 428 mg/m³
 AEROSOL Iron oxide OUTLET CONCENTRATION .014 gr/ft³ = 32.6 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm²/sec TOTAL MASS EFFICIENCY .924
 FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 203 °F = 95 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	15	15.0	= .424
INLET IMPACTOR	0.5	= .014	15	7.5	= .212
OUTLET TOTAL FILTER	1.0	= .028	84	84	= 2.38
OUTLET IMPACTOR	0.5	= .014	120	60	= 1.70

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	2.8	≤ .18*	--
2	8.6 - 13.6	3.3	.24	92.9
3	5.6 - 8.6	10.8	.29	97.3
4	4.0 - 5.6	16.5	.35	97.9
5	2.5 - 4.0	39.6	1.5	96.3
6	1.3 - 2.5	71.1	7.2	89.9
7	0.80 - 1.3	56.5	9.8	82.7
8	0.54 - 0.80	12.7	6.5	49.1
Final filter ≤ 0.54		≤ 1.4*	2.4	≤ 0 *
TOTAL, Andersen Impactor		213.	28.3	86.7

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 25 INLET CONCENTRATION .615 gr/ft³ = 1406 mg/m³
AEROSOL Iron oxide OUTLET CONCENTRATION .027 gr/ft³ = 62.9 mg/m³
NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY .955
FLOW: 1000 ft³/min = .28.3 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
TEMPERATURE: 70 °F = 21 °C

REMARKS: Approximately 10 ppm surfactant added to spray water.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	2.0	= .057	1.	2.0	= .057
INLET IMPACTOR	0.5	= .014	2.	1.0	= .028
OUTLET TOTAL FILTER	2.0	= .057	15.	30.	= 1.71
OUTLET IMPACTOR	0.5	= .014	15.	7.5	= .21

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	14.1	≤ 1.43*	--
2	8.6 - 13.6	24.7	≤ 1.43*	--
3	5.6 - 8.6	117.	≤ 1.43*	--
4	4.0 - 5.6	141.	≤ 1.43*	--
5	2.5 - 4.0	223.	1.89	99.2
6	1.3 - 2.5	307.	17.9	94.2
7	0.80 - 1.3	187.	28.3	84.9
8	0.54 - 0.80	21.2	8.0	62.2
Final filter ≤ 0.54		≤ 10.7*	1.89	≤ 82.2*
TOTAL, Andersen Impactor		1039.	58.0	94.4

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 26 INLET CONCENTRATION .121 gr/ft³ = 276 mg/m³
 AEROSOL Fly ash OUTLET CONCENTRATION .002 gr/ft³ = 3.9 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY 98.6
 FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min = 1.16 x 10⁻³ m³/sec
 TEMPERATURE: 85 °F = 29 °C

REMARKS:

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	25.	25.0	= .708
INLET IMPACTOR	0.5	= .014	25.	12.5	= .354
OUTLET TOTAL FILTER	1.0	= .028	268.	268.	= 7.58
OUTLET IMPACTOR	0.5	= .014	270.	135.	= 3.82

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	12.7	≤ .1 *	--
2	8.6 - 13.6	26.0	≤ .1 *	--
3	5.6 - 8.6	41.8	≤ .1 *	--
4	4.0 - 5.6	24.3	≤ .1 *	--
5	2.5 - 4.0	24.0	≤ .1 *	--
6	1.3 - 2.5	17.5	.7	96.0
7	0.80 - 1.3	10.5	1.4	86.7
8	0.54 - 0.80	≤ .8 *	.9	≤ 0 *
Final filter	≤ 0.54	≤ .8 *	.3	≤ 62.5 *
TOTAL, Andersen Impactor		158.	3.4	97.8

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 27

AEROSOL Fly Ash

NOZZLE: 200 psig = 1.4 x 10⁴ cm WC

FLOW: 500 ft³/min = 14.2 m³/min

TEMPERATURE: 200 °F = 95 °C

INLET CONCENTRATION .136 gr/ft³ = 311 mg/m³

OUTLET CONCENTRATION .002 gr/ft³ = 4.2 mg/m³

TOTAL MASS EFFICIENCY .986

Total Spray: 18.4 gal/min = 1.16 x 10³ m³/sec

REMARKS:

<u>SAMPLING DEVICE</u>	<u>FLOW RATE</u>		<u>DURATION</u> (min)	<u>TOTAL VOLUME</u>	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	25	25	= .708
INLET IMPACTOR	0.5	= .014	25	12.5	= .354
OUTLET TOTAL FILTER	1.0	= .028	243	243	= 6.88
OUTLET IMPACTOR	0.5	= .014	293	146.5	= 4.15

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL LII

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m^3)	OUTLET CONCENTRATION (mg/m^3)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	10.2	$\leq .07^*$	--
2	8.6 - 13.6	22.9	$\leq .07^*$	--
3	5.6 - 8.6	36.5	$\leq .07^*$	--
4	4.0 - 5.6	24.0	$\leq .07^*$	--
5	2.5 - 4.0	21.2	$\leq .07^*$	--
6	1.3 - 2.5	16.7	.58	96.5
7	0.80 - 1.3	11.6	1.4	87.7
8	0.54 - 0.80	1.7	.89	47.5
Final filter ≤ 0.54		$\leq .8^*$	.46	$\leq 45.8^*$
TOTAL, Andersen Impactor		145	3.4	97.7

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 28

AEROSOL IRON OXIDE (steam)

NOZZLE: 200 psig = 1.4 x 10⁴ cm WC

FLOW: 500 ft³/min = 14.2 m³/min

TEMPERATURE: °F = °C

INLET CONCENTRATION gr/ft³ = mg/m³

OUTLET CONCENTRATION .021 gr/ft³ = 47.8 mg/m³

TOTAL MASS EFFICIENCY

Total Spray: 18.4 gal/min

= 1.16 x 10⁻³ m³/sec

REMARKS: Spray introduced in inlet duct. Humidity ratio of approximately .044.

<u>SAMPLING DEVICE</u>	<u>FLOW RATE</u>		<u>DURATION</u> (min)	<u>TOTAL VOLUME</u>	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	Broken	= line, sample void		=	
INLET IMPACTOR	0.5	= .014	2	1	= .028
OUTLET TOTAL FILTER	1.0	= .028	15	15	= .42
OUTLET IMPACTOR	0.5	= .014	15	7.5	= .21

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m^3)	OUTLET CONCENTRATION (mg/m^3)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	67.1	$\leq 1.41^*$	--
2	8.6 - 13.6	110	$\leq 1.41^*$	--
3	5.6 - 8.6	216	$\leq 1.41^*$	--
4	4.0 - 5.6	216	$\leq 1.41^*$	--
5	2.5 - 4.0	251	1.88	99.3
6	1.3 - 2.5	318	16.0	95.0
7	0.80 - 1.3	198	28.3	85.7
8	0.54 - 0.80	28.3	14.6	48.4
Final filter ≤ 0.54		$\leq 10.6^*$	3.77	$\leq 64.4^*$
TOTAL, Andersen Impactor		1403	64.5	95.4

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 29	INLET CONCENTRATION .581 gr/ft ³ = 1329 mg/m ³
AEROSOL Iron Oxide	OUTLET CONCENTRATION .025 gr/ft ³ = 57.1 mg/m ³
NOZZLE: 200 psig = 1.4 x 10 ⁴ cm WC	TOTAL MASS EFFICIENCY .948
FLOW: 1500 ft ³ /min = 42.5 m ³ /min	Total Spray: 18.4 gal/min
TEMPERATURE: 70°F = 21°C	= 1.16 x 10 ⁻³ m ³ /sec

REMARKS:

Data corrected for leakage between inlet and outlet.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	2	2.0	= .056
INLET IMPACTOR	0.5	= .014	2	1.0	= .028
OUTLET TOTAL FILTER	2.0	= .056	15	30	= .85
OUTLET IMPACTOR	0.5	= .014	15	7.5	= .21

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL 111

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	10.6	≤ 1.41 *	--
2	8.6 - 13.6	28.3	≤ 1.41 *	--
3	5.6 - 8.6	81.3	≤ 1.41 *	--
4	4.0 - 5.6	67.1	≤ 1.41 *	--
5	2.5 - 4.0	134	3.30	97.0
6	1.3 - 2.5	177	18.8	87.1
7	0.80 - 1.3	134	27.8	75.0
8	0.54 - 0.80	≤ 10.6 *	7.07	≤ 19.4 *
Final filter	≤ 0.54	≤ 10.6 *	≤ 1.41 *	--
TOTAL, Andersen Impactor		633	58.4	88.9

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 30	INLET CONCENTRATION .571 gr/ft ³ = 1306mg/m ³
AEROSOL Iron Oxide	OUTLET CONCENTRATION .025 gr/ft ³ = 57.6mg/m ³
NOZZLE: 200 psig = 1.4 x 10 ⁴ cm WC	TOTAL MASS EFFICIENCY .947
FLOW: 1500 ft ³ /min = 42.5 m ³ /min	Total Spray: 18.4 gal/min
TEMPERATURE: 190°F = 88°C	= 1.16 x 10 ⁻³ m ³ /sec

REMARKS:

Data corrected for leakage between inlet and outlet.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0 = .028		2	2.0 = .056	
INLET IMPACTOR	0.5 = .014		2	1.0 = .028	
OUTLET TOTAL FILTER	2.0 = .056		15	30 = .85	
OUTLET IMPACTOR	0.5 = .014		15	7.5 = .21	

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	35.3	≤ 1.41*	--
2	8.6 - 13.6	63.6	≤ 1.41*	--
3	5.6 - 8.6	124	≤ 1.41*	--
4	4.0 - 5.6	106	≤ 1.41*	--
5	2.5 - 4.0	163	1.9	98.6
6	1.3 - 2.5	198	17.4	89.4
7	0.80 - 1.3	148	20.7	83.1
8	0.54 - 0.80	14.1	2.8	75.8
Final filter ≤ 0.54		≤ 10.6 *	≤ 1.41 *	-
TOTAL, Andersen Impactor		852	43.3	93.8

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 31 INLET CONCENTRATION .504 gr/ft³ = 1153 mg/m³
 AEROSOL Iron Oxide (steam) OUTLET CONCENTRATION .019 gr/ft³ = 44.4 mg/m³
 NOZZLE: 200 psig = 1.4 x 10⁴ cm WC TOTAL MASS EFFICIENCY .962
 FLOW: 500 ft³/min = 14.2 m³/min Total Spray: 18.4 gal/min
 TEMPERATURE: -°F = -°C = 1.16 x 10⁻³ m³/sec

REMARKS: Spray in inlet duct humidity ratio of approximately .072.

<u>SAMPLING DEVICE</u>	<u>FLOW RATE</u>		<u>DURATION</u>	<u>TOTAL VOLUME</u>	
	(ft ³ /min)	(m ³ /min)	(min)	(ft ³)	(m ³)
INLET TOTAL FILTER	1.0	= .028	5	5.0	= .14
INLET IMPACTOR	0.5	= .014	5	2.5	= .07
OUTLET TOTAL FILTER	1.0	= .028	25	25	= .70
OUTLET IMPACTOR	0.5	= .014	25	12.5	= .35

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥ 13.6	11.8	< .8 *	--
2	8.6 - 13.6	17.0	≤ .8 *	--
3	5.6 - 8.6	41.0	≤ .8 *	--
4	4.0 - 5.6	48.1	≤ .8 *	--
5	2.5 - 4.0	102	1.1	98.9
6	1.3 - 2.5	184	11.0	94.0
7	0.80 - 1.3	90.5	17.8	80.3
8	0.54 - 0.80	17.0	5.1	70.0
Final filter	≤ 0.54	≤ 4.2 *	≤ .8 *	-
TOTAL, Andersen Impactor		510	35.9	93.0

DYNACTOR SCRUBBER EFFICIENCY EVALUATION DATA

TEST # 32
 AEROSOL Iron Oxide
 NOZZLE: 200 psig = 1.4×10^4 cm WC
 FLOW: 1000 ft³/min = 28.3 m³/min Total Spray: 18.4 gal/min
 TEMPERATURE: 80°F = 27°C = 1.16×10^{-3} m³/sec

INLET CONCENTRATION .286 gr/ft³ = 654 mg/m³
 OUTLET CONCENTRATION - gr/ft³ = - mg/m³
 TOTAL MASS EFFICIENCY -

REMARKS: Downstream sampling done between the first and second Dynactor stages.

SAMPLING DEVICE	FLOW RATE		DURATION (min)	TOTAL VOLUME	
	(ft ³ /min)	(m ³ /min)		(ft ³)	(m ³)
INLET TOTAL FILTER	1.0 =	.028	3	3.0 =	.084
INLET IMPACTOR	0.5 =	.014	3	1.5 =	.042
OUTLET TOTAL FILTER	- = -	-	-	- = -	-
OUTLET IMPACTOR	0.5 =	.014	10	5.0 =	.14

FRACTIONAL EFFICIENCY DATA, ANDERSEN IMPACTOR, MODEL III

STAGE	AERODYNAMIC DIAMETER (μm)	INLET CONCENTRATION (mg/m ³)	OUTLET CONCENTRATION (mg/m ³)	FRACTIONAL MASS EFFICIENCY (percent)
1	≥13.6	14.1	≤ 2.1*	--
2	8.6 - 13.6	28.3	≤ 2.1*	--
3	5.6 - 8.6	70.7	2.8	96.0
4	4.0 - 5.6	80.1	6.4	92.1
5	2.5 - 4.0	127	19.1	85.0
6	1.3 - 2.5	184	53.7	70.8
7	0.80 - 1.3	130	38.9	70.0
8	0.54 - 0.80	16.5	6.4	61.4
Final filter	≤ 0.54	≤ 7.1*	≤ 2.1 *	-
TOTAL, Andersen Impactor		650	129	80.1